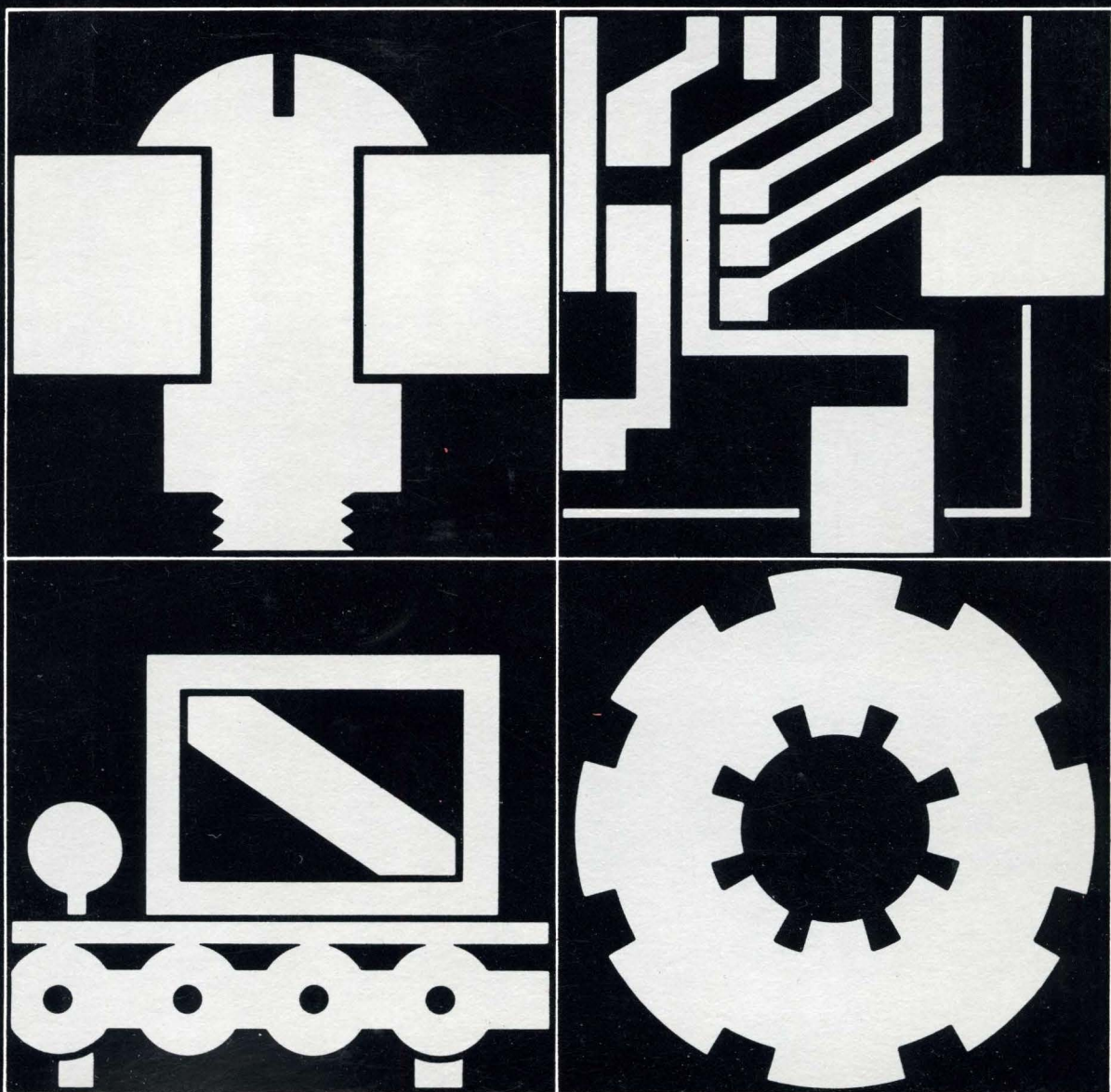


IBM

Communications Oriented Production Information and Control System

Volume V

Chapter 6 Manufacturing Activity Planning
Chapter 7 Order Release





Communications Oriented Production Information and Control System

Volume V

Chapter 6 Manufacturing Activity Planning
Chapter 7 Order Release

First Edition (March 1972)

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COPICS (Communications Oriented Production Information and Control System) is a series of concepts that outline an approach to an integrated computer-based manufacturing control system. The concepts deal with problems common to most companies, from a forecast of customer orders, through development of the master production schedule, to production and shipment of the product. COPICS is involved, therefore, with allocation and control of most of the major resources of a company — plant, equipment, manpower, and materials.

COPICS evolved from the approach to manufacturing applications presented in the IBM publication *The Production Information and Control System* (GE20-0280). In COPICS those applications are defined from a communications point of view and have been expanded in scope.

The twelve COPICS chapters provide management with a guide for development of a dynamic online manufacturing control system that is terminal and communications oriented and event responsive. The chapters present the system's concepts in a manner designed to help develop a system that can truly respond to the requirements of all levels of operating personnel and management. Little knowledge of computers is assumed, although some prior exposure to computer concepts and familiarity with such terms as "program", "files", etc., is helpful. Emphasis is on what the problems are and *why* their solution is valuable. How specific problems are solved is discussed only at that level of detail required to assure managers that the solution is feasible. The computer is not, itself, the system, but is, rather, a tool to be used by the manager.

The COPICS concepts are oriented to production and related manufacturing applications. They are not concerned directly with other major areas, such as finance, marketing, and personnel, although the COPICS approach collects data that will be helpful to these areas.

Throughout the COPICS publications, distinction is made between a given COPICS concept, the corresponding chapter, and the corresponding plant department by the use of small capital letters, italics, and initial capital letters, respectively. For example, reference may be made to the COPICS concept PURCHASING AND RECEIVING, or to material in *Chapter 10, Purchasing and Receiving*, or to the plant departments called Purchasing and Receiving.

The complete system is presented in eight volumes containing, in all, 17 sections. The Management Overview section is also available as a separate publication, G320-1230. The contents and IBM order numbers of the eight volumes are as follows:

Volume I	G320-1974	Management Overview, System Requirements, Index, Glossary
Volume II	G320-1975	Chapter 1 Engineering and Production Data Control Chapter 2 Customer Order Servicing
Volume III	G320-1976	Chapter 3 Forecasting Chapter 4 Master Production Schedule Planning
Volume IV	G320-1977	Chapter 5 Inventory Management
Volume V	G320-1978	Chapter 6 Manufacturing Activity Planning Chapter 7 Order Release
Volume VI	G320-1979	Chapter 8 Plant Monitoring and Control Chapter 9 Plant Maintenance
Volume VII	G320-1980	Chapter 10 Purchasing and Receiving Chapter 11 Stores Control Chapter 12 Cost Planning and Control
Volume VIII	G320-1981	System Data Base

To obtain the complete set of eight volumes please order the IBM Bill of Forms number GBOF-4115.

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The need for planning manufacturing activities

Most manufacturers share the following basic concerns:

- *Meeting order due dates.* The production schedule is the key plan that covers all work in the immediate future. Adherence to this schedule demands controlled order release, adequate capacity, and the ability to keep job priorities valid through all stages of production.
- *Controlling the level of work-in-process.* This type of inventory is costly both directly, in terms of investment, and indirectly, in terms of increased shop congestion, material handling costs, and floor space requirements.
- *Reducing manufacturing lead times.* Manufacturing lead times are usually longer than might reasonably be expected, yet short lead times can be a significant competitive advantage.
- *Controlling job queues at each work center.* Both lead time and work-in-process are minimized if a job is processed immediately on arrival at the work center. In practice this rarely happens, because other jobs simultaneously compete for use of the machine. Those jobs that have to wait accumulate in a work queue. The longer the queue, the longer the wait and lead times and the higher the level of work-in-process inventory.
- *Preventing bottlenecks.* When the rate at which jobs arrive at a machine consistently exceeds the rate at which they leave, a bottleneck results that can restrict the output of the entire plant. Even if the bottleneck is eased by increasing the daily work rate (for instance, by scheduling overtime), the sudden surge of output can create temporary bottlenecks at subsequent work centers.
- *Minimizing machine and manpower idle time.* One reason for the existence of job queues is that they safeguard against idle time. Neither foremen nor workers welcome idle time, and the knowledge that the queue is shrinking can cause a reduction in the work rate until the “normal” situation has been restored; queues therefore tend to grow until they fill the space available. Queues can be reduced if foremen become convinced that idle time will rarely occur.

Functions of Manufacturing Activity Planning

MANUFACTURING ACTIVITY PLANNING addresses these basic concerns of manufacturers by:

- Planning the capacity required at each work center and helping to allocate the machines and manpower required to meet the master production schedule
- Controlling the level of work-in-process by regulating the rate at which orders are released to the shop floor
- Helping to reduce manufacturing lead times by reducing the time a job must wait for a machine
- Planning and minimizing queue lengths to help ensure that machines and men will not run out of work
- Determining how much work can be transferred to alternate work centers in an effort to reduce overloads or fill idle capacity
- Analyzing remaining overloads and underloads to determine which orders can be subcontracted without causing idle time in other work centers
- Assisting in making short-term capacity adjustments by planning overtime, adding temporary extra shifts, or releasing subcontracted work
- Leveling the planned load on each machine center (in certain instances), thus reducing idle time, overtime, subcontracting, and amount of manpower movement between work centers
- Determining which orders should be released early to prevent idle time
- Accurately estimating the completion time for every shop order and customer order
- Planning the sequence of operations to be done at each work center and providing a work sequence list for the foreman and for PLANT MONITORING AND CONTROL

These functions are illustrated in Figure 1 and are described in this chapter under:

Capacity Requirements Planning

Priorities

Order Release Planning

Operation Sequencing

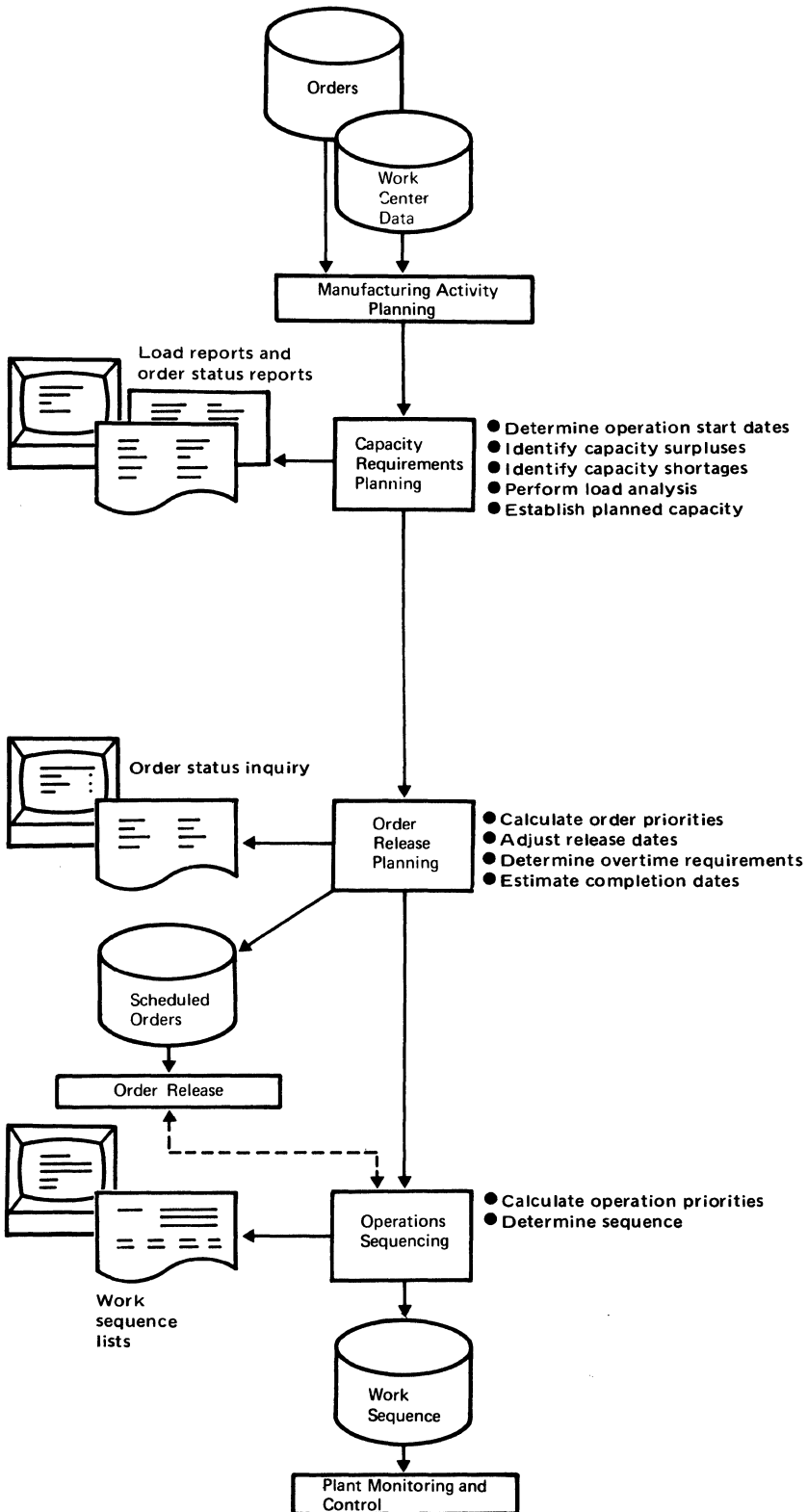


Figure 1. Basic functions of MANUFACTURING ACTIVITY PLANNING

- **CAPACITY REQUIREMENTS PLANNING** establishes the earliest and latest start dates for each job, calculates the capacity required to meet the master production schedule, and makes load balancing possible by providing the information necessary for detailed capacity adjustment decisions.
- Priority calculations can be made quickly and efficiently and plant management priority decisions consistently implemented by the system. Order priorities are considered by Order Release Planning, and both order and operation priorities by Operation Sequencing. The basic purpose of arranging orders by priority is to resolve contentions for production capacity.
- **ORDER RELEASE PLANNING** regulates the input to the plant by determining an order release date and estimated start date for each operation.
- **OPERATION SEQUENCING** provides the basis for assigning and dispatching work in the plant. Daily or at the end of each shift, it sequences, according to operation priorities, all work planned to be available during the next few days.

Relationship with other application areas

Figure 2 illustrates the relationship between **MANUFACTURING ACTIVITY PLANNING** and other areas included in the overall **COPICS** concept.

master
production
schedule
planning

MASTER PRODUCTION SCHEDULE PLANNING generates a master production schedule that is practical in terms of the overall planned capacity of the plant.

MANUFACTURING ACTIVITY PLANNING subsequently considers the detail of the same master production schedule. Capacities of individual work centers or machines are planned, rather than larger groups of resources. The impact of lot sizing of components is considered. This type of detailed planning reveals capacity problems that were not apparent in **MASTER PRODUCTION SCHEDULE PLANNING**.

inventory
management

INVENTORY MANAGEMENT generates planned orders for each item, based on the master production schedule. These orders, each represented by a quantity and a due date, are the prime input to **MANUFACTURING ACTIVITY PLANNING**. The workloads imposed by these planned orders, however, have not been balanced to the planned capacity.

MANUFACTURING ACTIVITY PLANNING adjusts order release dates, where possible, to utilize the anticipated capacity while minimizing short-term capacity adjustments and maintaining due dates.

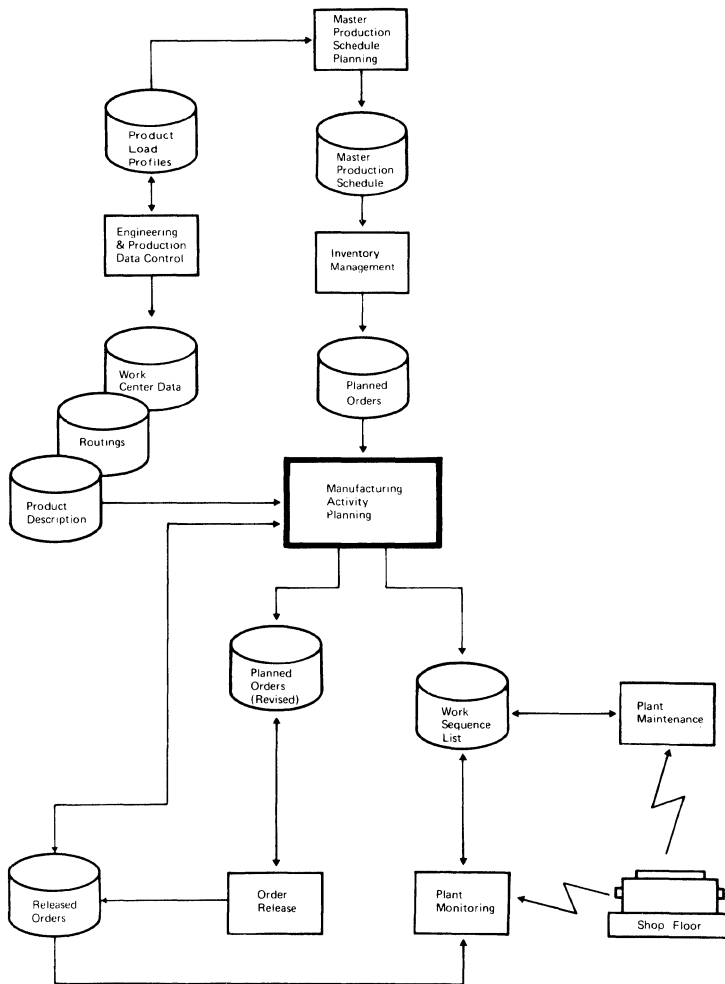


Figure 2. Relationship of MANUFACTURING ACTIVITY PLANNING with other areas of COPICS

order release	ORDER RELEASE extracts from the data base those orders ready for release, checks material and tool status, and produces shop documentation. MANUFACTURING ACTIVITY PLANNING determines the actual release date for each order.
plant monitoring and control	The work sequence list developed by OPERATION SEQUENCING in MANUFACTURING ACTIVITY PLANNING is the input to PLANT MONITORING AND CONTROL. It contains all operations to be performed over the next few days. Via a plant floor terminal, PLANT MONITORING AND CONTROL dispatches a new job to each worker on completion of the previous one. The dispatching sequence is suggested by OPERATION SEQUENCING and approved by the foreman.
engineering and production data control	ENGINEERING AND PRODUCTION DATA CONTROL maintains the basic engineering records used by the system. These include the manufacturing routing, machine, work center, and tool data required in MANUFACTURING ACTIVITY PLANNING.

Where Manufacturing Activity Planning applies

The MANUFACTURING ACTIVITY PLANNING concept is applicable to all companies that have a queuing and sequencing problem in balancing workload with production capacity. These include machine shops, foundries, and industries with repair shops and toolmaking departments. The techniques also apply in some process industries, for instance, some food processors, quality paper manufacturers, and raw material convertors that perform rolling, drawing, and extrusion.

Whether the various techniques utilized in the design of MANUFACTURING ACTIVITY PLANNING are applicable in a given case depends on the manufacturing environment. Not every technique applies to every environment. The important differences between manufacturing environments are of two kinds: the shop organization (work flow) and the stability of production requirements.

The conventional machine shop (job shop) has functionally organized departments equipped with multipurpose machine tools, and is characterized by parts orders that have dissimilar routing sequences and follow dissimilar paths through the shop. Contrasting with this environment is the line production shop with its production lines, transfer lines, assembly lines, etc., and the shop that groups machines and organizes departments around products being manufactured. These shops are characterized by the similarity of routing sequences for many parts within each of relatively few groups.

Manufacturing environments also vary in another important respect, namely, their relative stability. This stability, or the lack of it, is reflected in how frequently the master production schedule changes, how many engineering changes and routing alterations there are, how reliable the manufacturing process is, what the incidence of scrap (yield) is, and the rate of miscellaneous unplanned requirements for materials and parts.

In a highly unstable environment, open order due dates are subject to continuous revision, and material requirements, as well as capacity requirements, tend to deviate from original plans as a matter of course. In such an environment, emphasis must be on dynamic replanning rather than on elaborate detailed planning techniques, which could prove pointless in view of the high rate of change.

The applicability of the techniques of MANUFACTURING ACTIVITY PLANNING, relative to environment, is indicated as the various techniques are described in this chapter.

The following conditions are normally present in the industries that can utilize the MANUFACTURING ACTIVITY PLANNING concept:

- A routing identifying the operations and the required work center exists for most items manufactured.
- Work centers can be clearly identified.
- Operation times, either standards or estimates, can be determined.
- A relative priority can be associated with each order (this may be simply a due date).
- Production is lot-sized into predetermined quantities.

Definitions of Workload, Work Center, and Work Capacity

Definitions of workload, work center, and work capacity are essential. Differences in definition have led to much confusion in discussing manufacturing control systems. The following definitions are used in the discussions of the MANUFACTURING ACTIVITY PLANNING concept.

Workload

Every operation performed in the production of an order that requires a production facility imposes a workload. Each operation on a routing normally specifies a setup time, a run time per piece, and possibly a “teardown” time (for instance, when a jig has to be removed on completion of the operation).

Each of these elements imposes a load on the specified machine center, but it is also possible for different labor groups to be involved. These labor groups can also be specified in the routing, and each can be treated as a production facility. The system accumulates the total workload by time period on every work center. The workload represents the capacity requirement that must be met if the schedule is to be achieved.

Work Center

A work center is a group of machines or men specified in the routing to perform a particular operation. It may consist of one or several men or machines.

In continuous production a work center may consist of different types of machines or areas that are used together to perform a given set of tasks on a product.

In a job shop, a work center normally consists of a group of like machines or a group of men with similar skills.

Shops may also contain groups of dissimilar machines associated together in making a particular type of product. They may be specified either as one work center or as multiple work centers, depending on the degree of planning detail required.

If work centers are defined too broadly (for example, “turning department”), it may appear that the capacity of the center is adequate to meet the load, when in fact engine lathes are badly overloaded and turret lathes are short of work.

On the other hand, the definition of each individual machine as a work center would make scheduling procedures unnecessarily complicated. However, when a single “key” machine or specified labor group must be carefully controlled, it should be designated as a separate work center. For instance, a high-precision drill in operation almost 24 hours a day would be designated as a separate work center.

The grouping of machines into the same work center need not imply that each machine can perform any operation assigned to this work center; close-tolerance work may not be possible on old machines, and men in the same group may have different skills. These differences can generally be ignored for long- or medium-range planning, but in OPERATION SEQUENCING it may be desirable to subdivide a work center into:

- Subgroups based on tolerances, skill classification, etc.
- Individual machines having special attachments, tools, etc.

Alternate work centers

When any operation normally performed by a given work center can also be done elsewhere, the other work center can be specified as an alternative. For example, Universal Mills may be an alternative for Plain Mills (but not necessarily vice versa). Alternate work centers may or may not be located in the same plant. For planning purposes, a subcontractor can also be considered as an alternate work center.

Work Capacity

Capacity is a measure of possible work output over a given period of time. In a steel mill, it might be defined as the total tonnage produced in a seven-day week, working 24 hours a day.

Many manufacturing companies work a 5-day, 40-hour week; normal capacity can then be based on a 40-hour week. However, even the value of 40 is not exact, since allowances must be made for scheduled breaks and other losses.

In this chapter it is convenient to consider the daily capacity of a work center. This can be derived from the following information:

- The number of men and machines available in each shift
- The number of available hours per shift (excluding lunch, rest breaks, and cleanup allowances)

Shift	Shift Hours	Number of Machines	Number of Men	Daily Machine Capacity (Hours)	Daily Labor Capacity (Hours)
1	8	10	6	80	48
2	8	10	6	80	48
3	4	10	1	40	4
Totals				200	100

Allowance for scheduled breaks, indirect losses, etc.	= 10 %
Adjusted daily labor capacity	= 90 hours
Adjusted daily machine capacity	= 180 hours
Work center efficiency factor	= 120 %
Effective daily labor capacity	= $90 \times \frac{120}{100} = 108$ hours
Effective daily machine capacity	= $180 \times \frac{120}{100} = 216$ hours

Figure 3. Work center capacity is adjusted for scheduled rest breaks, indirect labor losses, and work center efficiency to derive an “effective work center capacity”

An example is given in Figure 3. In this case, the available labor capacity is considerably less than the machine capacity. Labor is most often the limiting factor in capacity planning. When machines have consistently high loads, however, their capacity may be the limiting factor; that is, loss of their capacity would seriously jeopardize the schedule. They are referred to as “critical” work centers.

Allowance for work center efficiency

The workload imposed by an operation on a work center is usually derived from the standard times quoted in the routing. These standard times do not, however, represent the time it actually takes to do the job. They merely form a base on which the worker is paid or rated. If workers are paid on an incentive basis, most operations are performed in less than standard time.

Consequently, any comparison of workload against work center capacity must allow for this discrepancy. The difference between standard and actual time for a given work center is expressed as an “efficiency factor”. Its value must be applied to actual capacity values. The resultant figure is the effective work center capacity. Future references to capacity assume that these adjustments have been made.

Specifying variations in capacity

Work center capacity may vary week by week and day by day. It varies with the assigned labor force, the shift lengths, and the amount of overtime. It is also affected by vacations and illness. All these variations must be reflected in the system.

Within a specified time period, capacity is considered flexible. It is common practice to specify two capacity levels: “normal” and “maximum”. The difference between these reflects the possibility of arranging overtime, adding temporary extra shifts, or obtaining additional labor (Figure 4). Note that in the short term, where the capacity is committed, no capacity flexibility is designated. In practice, it will vary because of disruptions, absenteeism, breakdowns, etc. Variations in capacity during this period will be entered in PLANT MONITORING AND CONTROL and utilized during the short-term OPERATION SEQUENCING.

The maximum capacity can be specified in actual hours, or be derived from the normal capacity by adding an “overload tolerance percentage”.

Exact definition of capacity is important in the short term, particularly in the case of “critical” work centers. In some cases, however, definition is not necessary because capacity is never fully utilized, or is practically unlimited (for instance, at a center cutting raw materials). In other cases it cannot be expressed in relation to operation times. Heat treatment, for instance, can be performed simultaneously on a variety of jobs, and the relationship between load and capacity depends largely on the volume, shape, and mix of items, which is difficult to express quantitatively. Where definition is impossible, no capacity is considered.

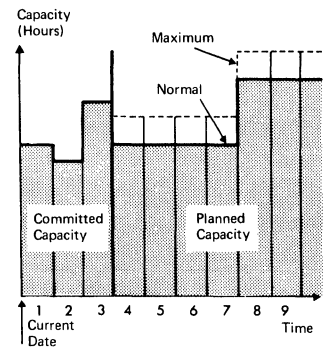


Figure 4. Planned capacities vary from day to day

The Vicious Circle

The problems of lead time, work-in-process, and capacity are interrelated; in fact, they can be self-perpetuating. In Figure 5, for example, as a company's business improves, more orders are released to the plant. If the work input is greater than the work capacity, and queues build up at the work centers, jobs have to wait longer. As a result, customer orders are late. The foremen feel that given two weeks more lead time they could complete orders on schedule, so the manufacturing lead times are accordingly increased by two weeks.

New shop orders are now released two weeks *earlier*, generating an additional two weeks' volume of work on the plant floor. This increases both work-in-process and queue length some more. Lead times become longer than ever, and orders are still finished behind schedule. If the manufacturing lead times are further increased, shop orders are placed earlier still and queues get even larger. Work-in-process goes up, but without an increase in capacity there is no improvement in customer delivery service.

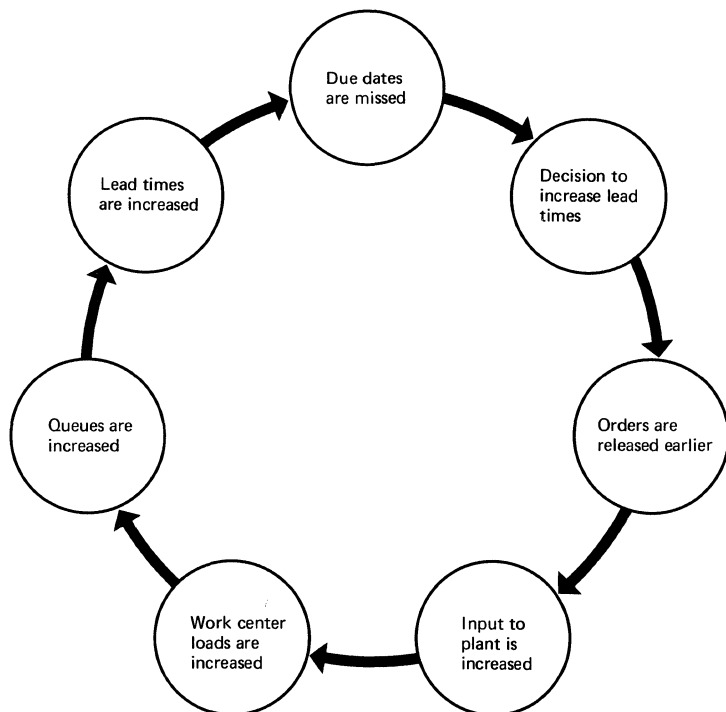


Figure 5. The solution to an increasing number of late orders is not to release work to the shop floor earlier. A *vicious circle* of events is created which compounds the problem

If longer hours are worked in order to remove the bottlenecks, work will get out faster and Production Control will be under pressure from management to reduce lead times. If manufacturing lead time were suddenly reduced by two weeks, very few shop orders would be released for a period of two weeks. Work-in-process would decrease, queues would become shorter, and future shop orders could be completed in less time.

Arbitrary decisions to increase manufacturing lead times are not conducive to a stable production situation. Lead times should be governed by the amount of time it takes to move jobs from operation to operation, by the average amount of time each job has to wait at each work center under normal conditions, and by the time it takes to perform the operation. A stable production situation results from controlled throughput. This, in turn, requires that capacity be adequate to meet the demand on the plant; only then can production lead times be accurately estimated and order due dates consistently achieved.

Control of Queues

In the vicious circle just described, the actual lead times exceeded planned lead times because of a capacity shortage and the order due dates were then missed. The planned lead times were no longer accurate for one simple reason: job queues had increased and jobs spent too much time waiting to be processed. The solution: to reduce lead time, reduce the queues; to control lead times, control the queues. Excessive queues and unplanned increases in queue length cause order delays, unrealistic start dates, and shop floor congestion.

Even in a well controlled situation, an order typically spends much more time waiting in queues than actually being processed. A ratio of ten hours waiting to one on the machine is not unusual. Thus control of the time spent waiting allows significant reductions in lead time.

A queue at a work center can be compared to water in a tank (Figure 6). The output of a work center is limited by its work capacity; the output from the tank by the dimensions of the outlet. There are three possible situations:

- If input equals output, the queue (water level) stays constant.
- If input exceeds output, the queue increases.
- If output exceeds input, the queue decreases.

A queue can be decreased only by increasing the output or decreasing the input. If this continues to happen over a period of time, the queue eventually disappears and idle time results. On the other hand, if the input to a work center consistently exceeds the output, the queue grows steadily longer.

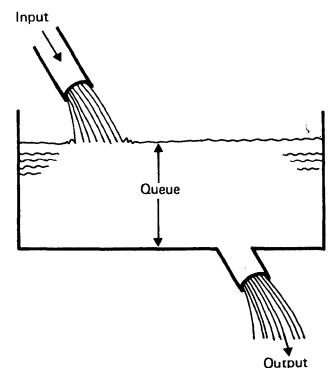


Figure 6. If the output rate is the same as the input rate, the queue size stays the same

Even if there is perfect balance between work input and output, the queue can be excessive; this is because once a queue is there, it is not reduced unless output exceeds input. The unnecessary “buffer” becomes a permanent establishment.

Therefore, there are two problems to be resolved if queues are to be adequately controlled. First, detect and remove any unnecessary buffers of work; second, maintain a balance between work input and output by providing adequate capacity where required.

Balancing the production line

In production line manufacturing, the balancing of input and output is comparatively simple to achieve because all work follows the same route. The capacity of each work station on the line is balanced to ensure a steady flow of work. Therefore, it is only necessary to regulate the input at the first station in accordance with the desired rate of the line.

In some cases, the principle can be applied in a conventional machine shop. Where volume is sufficient, machines can be arranged in groups similar to production lines. Each group processes a “family” of similar parts, for example, hydraulic valves. Each group is a “machining cell”. This approach reduces setup changes and job movement, and if the machine capacities are balanced correctly, jobs spend little time in queue.

In most machine shops, there is a limit to the number of machines that can be grouped in this way. This is because few items can be categorized into families able to utilize fully a series of machines.

Balancing capacity — controlling the output

Production costs can be held to a minimum if production is maintained at a relatively constant rate. It is generally not possible or economical to vary constantly the labor force to meet fluctuating workloads at short notice. In many cases the output rate of the “final assembly” department is stabilized and the other supporting machine centers are expected to solve their own problems.

Variations in the product mix, however, will cause substantial variations in the load on the fabrication shop (Figure 7).

Capacity also is often difficult to balance because the machine shop configuration, having been determined years ago by products manufactured then, bears little relation to the current mix of products; for example, it may now have too much turning and not enough milling capacity. Maximum machine utilization is generally possible only if the capacity has been set to a level compatible with current production requirements.

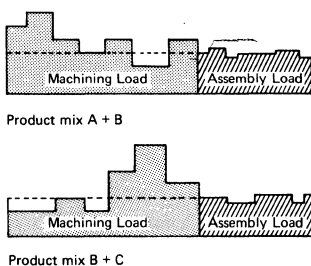


Figure 7. Balanced assembly operations may cause uneven loads on fabrication departments

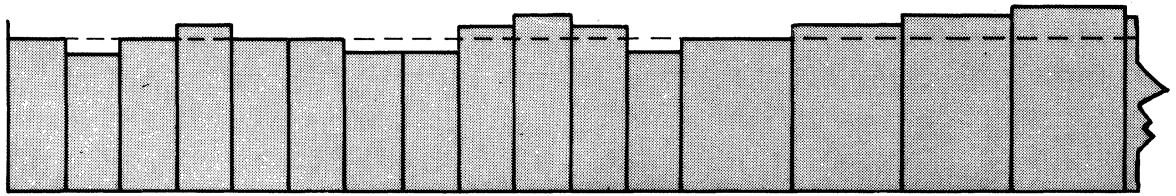
Balancing the capacity starts with determining in advance the capacity requirements (workloads) and planning adjustments to the available capacities. These adjustments can be made by:

- Acquiring new plant and equipment
- Increasing or reducing the work force
- Subcontracting, or performing work for other plants
- Planning extra shifts
- Planning overtime work

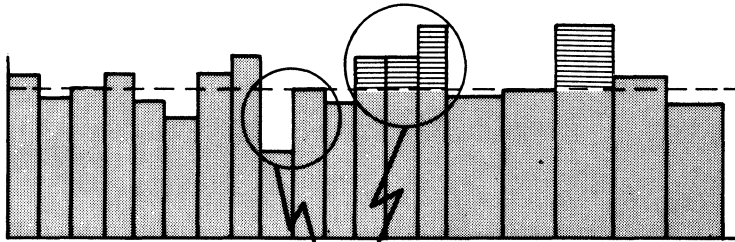
Efficient planning and balancing of capacity is achieved in several stages, corresponding to the length of the planning horizon. This is necessary in order to cut the problems down to a manageable size at each stage. Capacity is never static and workloads are constantly changing, so detailed planning too far out in the future is wasted effort. For instance, it may take twelve weeks to hire and train labor, and it is pointless to plan overtime for them until it is known what the work force is actually going to be.

As Figure 8 shows, the stages involved are:

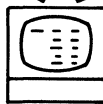
- Getting the gross overall balance right by making sure that the master production schedule is feasible with the projected plant capacities. This is designed into MASTER PRODUCTION SCHEDULE PLANNING. Monthly or quarterly time periods are normally used, and the time span may be several years. Capacity decisions involve plant, equipment, and manpower.
- Determining, once a realistic schedule is established, the required rates of output and the likely overloads and underloads at the work centers, based on the planned order schedule produced by INVENTORY MANAGEMENT. This is the function of CAPACITY REQUIREMENTS PLANNING. Capacity adjustments include timing production machine deliveries, making arrangements for subcontract work, or planning the transfer of labor resources. Weekly or monthly time periods are appropriate for this stage, and the horizon may extend for several months.
- Using ORDER RELEASE PLANNING to provide enough detail for planning overtime and issuing subcontract orders. Order release dates may be adjusted for the plant's input to agree with the planned capacity. If capacity has been planned fairly well in CAPACITY REQUIREMENTS PLANNING, few adjustments are required. The planning horizon is in days and weeks for several weeks out.



Master Production Schedule Planning

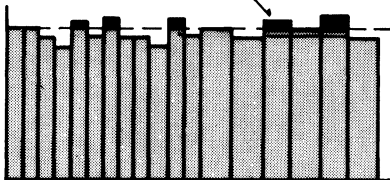


Capacity Requirements Planning



Overload and
underload
analysis

Overtime planning



Order Release Planning



Operation Sequencing

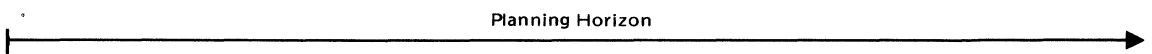


Figure 8. Capacity planning is done in several stages. These stages vary corresponding to the length of the planning horizon and the amount of detail

- Determining, for the queue of jobs at every work center, the sequence that best utilizes the planned capacity and meets the order dates. This is done in OPERATION SEQUENCING, usually on a daily or shift basis. OPERATION SEQUENCING simulates the minute-by-minute situation on the shop floor, while looking at the overall requirements of the plant. This enables accurate sequencing decisions to be made.
- Measuring the rate of output, by work center, to verify that actual capacity is meeting capacity requirements planned previously. This is accomplished in PLANT MONITORING AND CONTROL.

Releasing the order

In many plants input to the shop is erratic. The number of shop orders issued may be fairly constant, but the machine loads that these orders impose may vary considerably (Figure 9).

Two other factors affect input. First, production control departments often feel more secure when they release orders to the plant as soon as possible, because they cannot then be held responsible for holding up production. Second, if a work center's queue is reduced too much for the foreman's comfort, there is usually pressure to release more orders.

Such decisions have the effect of alleviating the current problem (for example, precluding idle time in certain work centers), but they may also cause increased queues and chaos in other departments at a later point.

In other plants, more or less arbitrary rules govern the choice of orders to be released. For instance:

- Release all orders for September production as soon as possible.
- Issue all orders for a particular customer contract.
- Issue 500 hours of milling work next week.

This broad approach rarely achieves results that are satisfactory. The problem is to know *which* of the orders out of September's production, or for a particular contract, should be released to meet overall production objectives. Some orders may have to be released earlier than the dates originally planned, and some orders later. For shop orders, the feasibility of changing planned release dates will depend on the environment and on the availability of raw material and components. *The number of adjustments to be made depends on the effectiveness of the previous stages of capacity planning*, that is, how well the output was planned. The function of ORDER RELEASE PLANNING is to make adjustments to order release dates, but *only* if capacities cannot be economically adjusted.

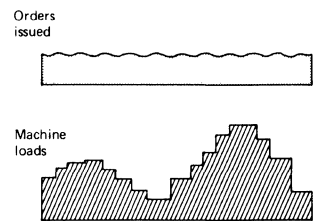


Figure 9. A constant rate of order release imposes a varying load on the shop floor

In a production line environment, control of input is relatively simple and can be done by balancing the input against the output from the line. This is normally governed by the number of men assigned. In a job shop the input to the first-operation, or “gateway”, work centers can be similarly controlled. However, most companies have an average of five, six, or more operations per part. Machines are multipurpose and the flow of work is to a certain extent random (Figure 10).

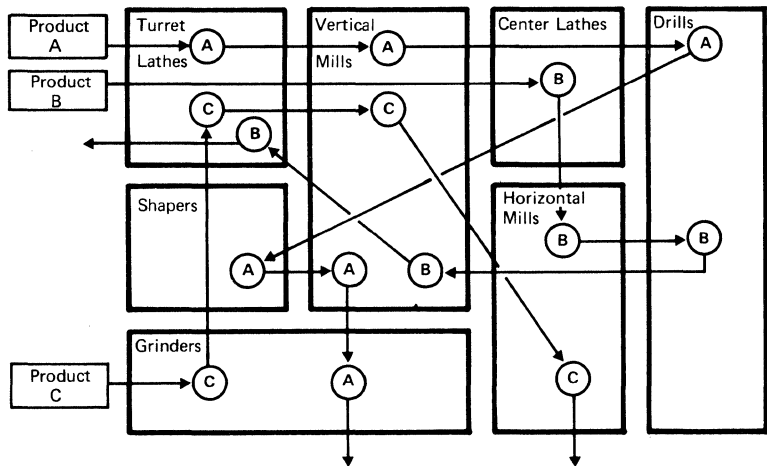


Figure 10. The flow of work in a job shop varies for each item, thus complicating the release of orders to the floor

In this situation, controlling the release of work to only the gateway center is not very effective. However, controlling the input to the other work centers is considerably more difficult to do. This is because their input is the combined output from many previous work centers and varies with product mix, routing sequence, and the operation durations.

In the job shop environment, and particularly under conditions of relative instability, input to the shop is governed by MATERIAL REQUIREMENTS PLANNING, which generates all planned order release dates as well as raw material order due dates. The emphasis of MANUFACTURING ACTIVITY PLANNING is on planning capacity, determining output rates required, and controlling actual output by work center.

In a line production or “machining cell” environment, and under more stable conditions generally, MANUFACTURING ACTIVITY PLANNING addresses the problem of input control not just for the gateway center but for *all* work centers. ORDER RELEASE PLANNING and OPERATION SEQUENCING adjust order release and operation start dates in such a way as to ensure a fully controlled workflow through the shop.

Capacity Requirements Planning

The basic function of CAPACITY REQUIREMENTS PLANNING is to determine the workload (capacity requirements) by time period for each work center, based on the planned order schedule supplied by INVENTORY MANAGEMENT. The output is basically a series of load “profiles” indicating where (in a reasonably steady environment) overloads and underloads are likely to occur – unless capacities are adjusted (Figure 11). Effective planning ensures that capacities and loads are balanced; only this way can idle time be minimized and on-schedule delivery assured. CAPACITY REQUIREMENTS PLANNING makes load balancing possible by providing the information necessary to set the required output rates and for detailed capacity adjustment decisions.

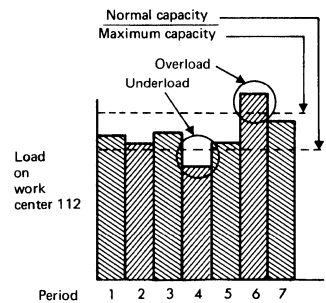


Figure 11. A “load profile” is generated showing the overloads and underloads on each work center

The basic steps in CAPACITY REQUIREMENTS PLANNING are:

- Determine the various elements comprising the manufacturing lead time. This includes time spent on the machine, and time spent between operations such as queue time, transportation time, etc.
- Determine the estimated start date for each operation. This is done by starting from the due date of the order and subtracting the various lead time allowances. If the start dates for some operations fall into the past, the system attempts to hold the schedule by applying techniques such as compressing queue time and overlapping operations. If these techniques are not successful, the system reports which due dates should be revised to make the schedule more realistic.
- Calculate work center capacity requirements by period and pinpoint overloads and underloads. Determine planned rates of output by averaging capacity requirements over multiple periods. The planner can alter planned capacity via a terminal and see the immediate effect of his decision on the load patterns.
- Alleviate unresolved load problems by identifying individual orders that are the best candidates for rescheduling.

Manufacturing Lead Time

Since load profiles show work center loads by time period, they can be produced only by scheduling individual operations within the order. This means that the probable start date of each operation must be estimated.

To schedule the start dates for operations, the time required for each individual manufacturing function must be estimated. The sum of these times constitutes the manufacturing lead time. Total manufacturing lead time for an order is the interval between its release to the shop floor and its delivery to stores or assembly. It includes the time required to cut off material or withdraw parts from stores. Lead times are made up of several time elements, and these fall into two basic categories (Figure 12):

- Operation duration, which is the time the job actually spends on the machine. This includes setup time as well as actual production time.
- Interoperation time, which is the time the job spends being moved and inspected, waiting in queue, etc., but not being processed.

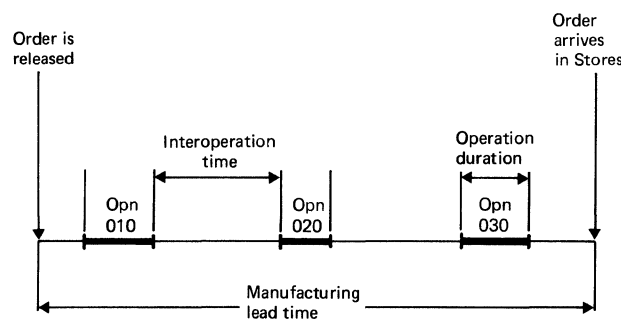


Figure 12. Manufacturing lead time can be classified into time spent on the machine and time between machine operations

The estimated operation run times depend on the order quantity (lot size) but interoperation times vary considerably depending on conditions in the shop at the time — overloads, idle time, etc. Interoperation times and, in particular, the time the job waits in work center queues largely determine manufacturing lead time.

Operation duration

Most data for determining operation time comes from the Manufacturing Routing, which specifies the sequence of work to be done and the standard times. Routings are sometimes referred to as route sheets, process sheets, operation layouts, or planning sheets. They specify, for each operation, a standard setup time, a run time per piece, and perhaps a teardown time.

The operation duration is calculated by:

- Extending the number of items on the order by the standard time per piece (or per 100, per 1000, etc.) to get standard run time.
- Adding standard setup time to the running hours to get hours of machine time required at standard.

- Dividing the hours by a length-of-day factor expressing the number of standard hours in a day. This factor, which varies by work center, depends on:

The estimated loss of time because of lunch and break allowances, indirect labor, rework, etc. (expressed as a percentage)

The efficiency factor of the work center (expressed as a percentage)

The normal length of a working day

If loss of time is 10% and the work center's efficiency factor is 120%, then an eight-hour shift is 8.64 hours at standard ($8 \times .90 \times 1.20 = 8.64$). (In the following discussions, it is assumed the hours have already been adjusted.)

The normal length of a working day depends on the number of men, or machines, in the center that normally work on a job in a day (Figure 13). If one man works one shift, the length-of-day factor is 8 hours; if normally two men work simultaneously on a job, it is 16 hours; if two shifts per day is normal, it is 16 hours; if 10% overtime is normal, it is 8.8 hours. If setup is also performed by several men, this too must be taken into account.

Some industries have tight control over their time standards and can determine operation run time quite accurately. Other industries have no standard times per operation, but work to an estimated time. Even industries with well established time standards introduce new operations and use estimated standards until accurate ones are established. Most rework is done using estimated standards. Departments performing prototype development, or repair shops, may never establish accurate standards.

The more accurate the time standards are, the better will be the plan. However, it should be realized that MANUFACTURING ACTIVITY PLANNING can be used effectively even when only rough estimates of operation durations are available. It is not just a case of inaccurate planning being better than no planning at all, but a case of "relative accuracy".

For instance:

- Loads are summarized by time periods of one week to one month. A small inaccuracy will only shift some load from one period to another. The load profiles generated give a relative picture of where overloads and underloads will occur and are more important than the exact amount of load in a particular period.
- Scheduled start dates for operations are determined largely by interoperation times rather than operation durations. This is because run time is usually only 10-20% of total time on the floor.

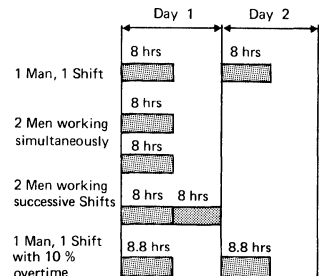


Figure 13. Different factors can be used to convert hours into days of operation duration

accuracy of
time
standards

- As already indicated, capacity levels are adjusted to allow for an historical efficiency factor, making the estimated times more accurate.
- The sequence in which work is performed depends more on order and operation priorities and machine availability than on operation times.

Where no standard or estimated time exists (say, for a new routing or an added operation), a “substitute time”, which varies by work center, can be used. As an example, the average run time for jobs on engine lathes may be two hours. This figure would be automatically used for any operation with no time standard.

Interoperation time

Interoperation time is the interval between the completion of one operation and the start of the next operation on the same order.

In assembly lines, the regular flow of work from station to station normally prevents the accumulation of work between stations. Here the interoperation time is relatively short.

On the other hand, in a job shop where operations compete for capacity, where work queues develop, and where the work centers are some distance apart, interoperation times are significant.

The interoperation interval comprises several time elements — in some cases, as many as five (Figure 14):

- Queue time (waiting to be assigned to a machine)
- Preparation time (marking out, cleaning, etc.)
- Postoperation time (inspection, cooling, etc.)
- Wait time (awaiting transportation)
- Transport time (for transportation to the next work center)

All elements except transport time are work center dependent. Transport time depends on the location of the two work centers involved, and values for it can be provided in matrix form.

Not all of these elements have to be specified for every work center. For example, wait time can be expressed as a single value — say half a day — for all operations, or in many work centers the unnecessary elements can be expressed as zero.

For critical work centers where close throughput control is desirable, all five elements may be specified.

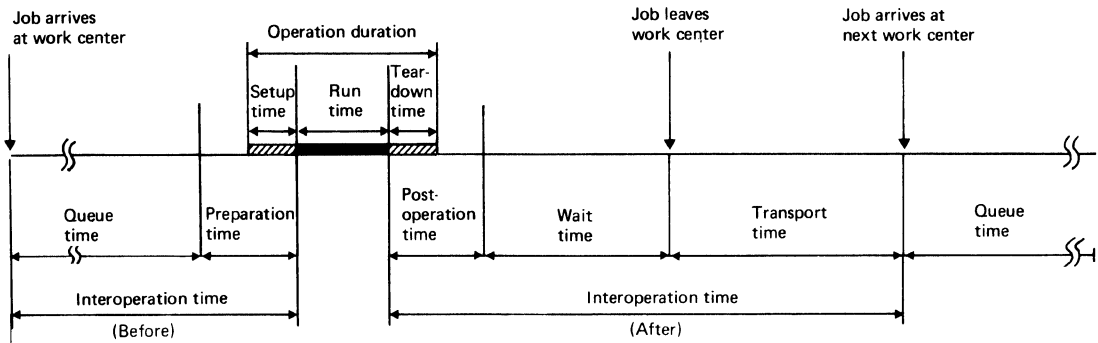


Figure 14. Interoperation time is made up of several elements

The queue time quoted for each work center should be based on the assumption that a controlled situation can and will be maintained.

queue time
and queue
size

What then should be the planned size of queue? The planned size of the queue determines the average length of time a job must wait at a work center. Because of the many unrelated factors that go to make up a queue, an “optimum” queue size is difficult to determine.

The problem can be illustrated by considering a simple case of two machines, one feeding the other. If both have the same output rate, there need be no queue at the second machine. However, if the first machine has a planned utilization of 80% but temporarily achieves 90% (that is, its output increases), work builds up in front of the second machine (Figure 15). A queue also builds if the second machine slows down.

If, at the first machine, work is scrapped or materials and tools are not available, or if the machine itself goes down, the flow of work to the second machine fluctuates or may even stop, and the queue quickly decreases.

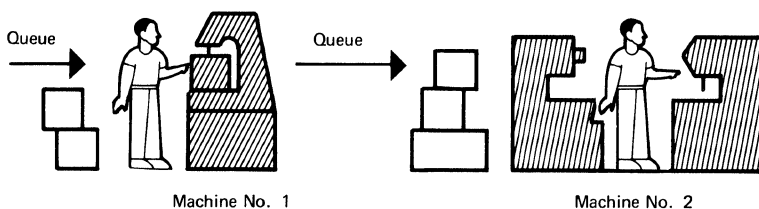


Figure 15. The primary factor affecting the size of the queue is the difference between the work center's job input and job output rate

Therefore, a queue is required as insurance against idle time. Queues absorb variations in the work arrival rate caused by machines going down, operators getting sick, changes in efficiency, variation in operation time, scrap, or just randomness in job length and product mix.

Even in the simple case of two machines, it is not easy to determine what length of queue should be planned. Where one work center receives input from many others, the difficulty is compounded.

In practice, therefore, values for queue time are normally derived from past observations. Variations in past queue size give a better picture of what the planned queue size should be than the actual queue length itself. The value used for queue time states the average queue size, say 200 hours, and the normal range or variation of the queue size, say 100 to 300 hours. In this case, the queue could be reduced by up to 100 hours without affecting the output of the work center (see Figure 16B).

Determining whether the queue length is unreasonable can be done by analyzing past observations of queue size. The necessary data is maintained by PLANT MONITORING AND CONTROL, which takes “snapshots” of the actual queue size at frequent intervals. The size of the queue at each point in time is recorded. These values can be represented by a frequency distribution (Figure 16).

Diagram A indicates the situation at a work center with a reasonable queue. The queue length is rarely zero, indicating negligible idle time. The distribution of queue sizes approximates a statistically normal distribution. This is an indication that the various factors influencing queue size occur randomly. Statistical techniques are used to predict the average queue length in this situation.

Diagram B represents a work center with full utilization of capacity but a persistent backlog of work. The queue size has hardly ever been less than 100 hours, representing an unnecessary buffer. Removal of 100 hours of queue would reduce the average waiting time of all future orders. That is, if this center produced 20 hours of work per day, the production lead time would be reduced by 5 days ($100 \div 20$). If queue size has historically been between 100 and 300 hours, with an average of 200, then an average of 100 hours, with a range of 0 to 200, would eliminate 5 days in lead time and still result in minimal idle time.

Diagram C represents a work center with a highly variable queue length, indicating frequent overload situations. MANUFACTURING ACTIVITY PLANNING minimizes the incidence of such situations.

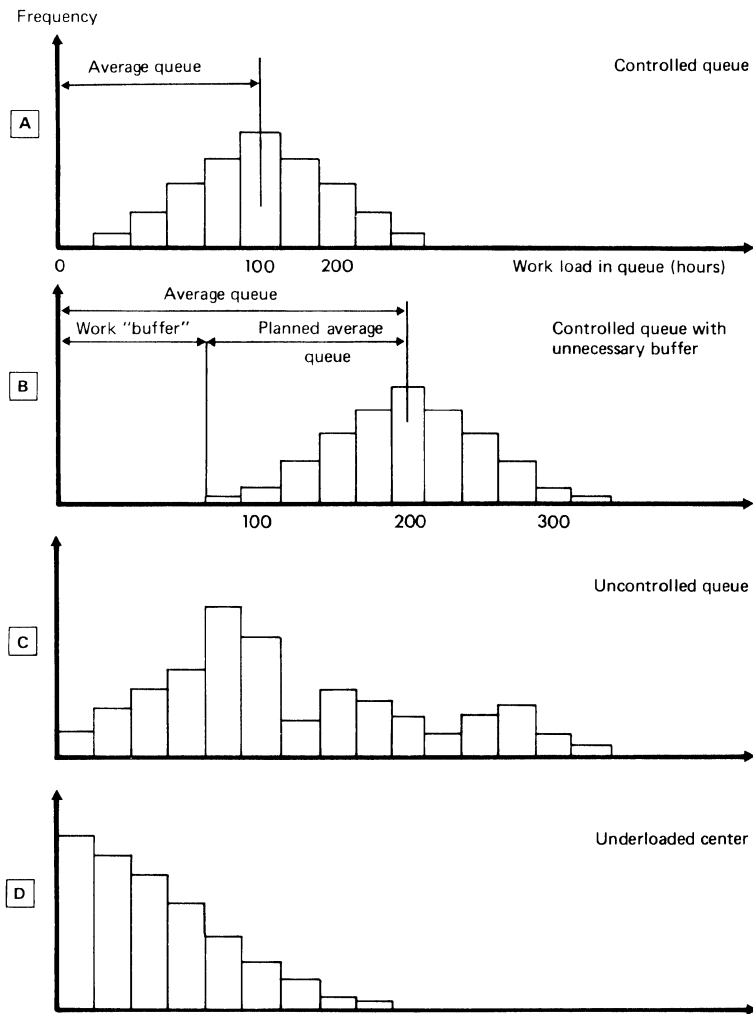


Figure 16. The average size of the queue can be distributed in several ways. The system's objective is situation A

The work center represented in Diagram D has been persistently underloaded and the queues have been correspondingly short. Statistical techniques assuming normal distribution of queue size would not work. Instead an "exponential" statistical distribution can be used to calculate average queue size.

Where applicable, management can use the calculated distributions of queue size to balance the cost of longer lead times and more work-in-process against the cost of idle time. Management can alter one factor and change the relationship between the level of work-in-process inventory and idle time on the production facility (Figure 17).

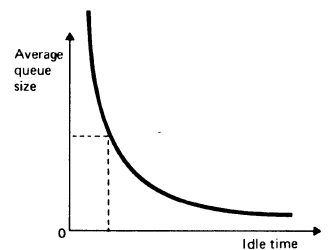


Figure 17. The amount of idle time at a work center may vary with the average queue size

Queue time analysis detects excessively long or short queues for management action. It also establishes “reasonable” or average values for the queue time element of interoperation time for each work center. Once a reasonable queue time is established, it is used in determining a *planned* order lead time for use in MATERIAL REQUIREMENTS PLANNING and CAPACITY REQUIREMENTS PLANNING. This lead time, in turn, determines the dates when loads are imposed on work centers.

preparation time	Another element of interoperation time is preparation time, which may be specified for each work center. It represents work that must be done before the operation can begin, but for which no time estimate is given in the routing (say cleaning, heating, marking out, or setup, if not otherwise specified). The preparation time can be different for each work center and is expressed as one of the following: ■ A percentage of the operation duration (marking out for jig boring, for example, takes an average 10% of the operation duration) ■ A time per unit (say 12 minutes per 100 pieces) ■ An average time per order
postoperation time	The postoperation time represents production activity occurring after completion of the operation but not represented in the routing. Such work imposes no load on the defined work centers. Examples are deburring, cleaning, wrapping, cooling and local inspection. Values for postoperation time can be expressed for each work center in the same way as preparation time values: cooling (after heat treatment) may take, say, 120% of the heating time, or 24 hours; inspection time can be specified as 10% of the operation time, or as a fixed value.
wait time	Wait time represents the time the material spends waiting for transportation to the next work center. This interval depends on the resources and efficiency of the materials handling department. PLANT MONITORING AND CONTROL provides statistical averages of wait time. The average will usually vary by the type of materials handling equipment required and not by work center.
transportation time	Transportation time depends on the location of the work centers involved, i.e., on the origin and destination of the move. If this time is significant, each work center can accordingly be given a “location code”, corresponding to a department, building or plant. The transportation times are stored in a table (Figure 18). The statistics on transport times are provided by historical averages maintained in PLANT MONITORING AND CONTROL.

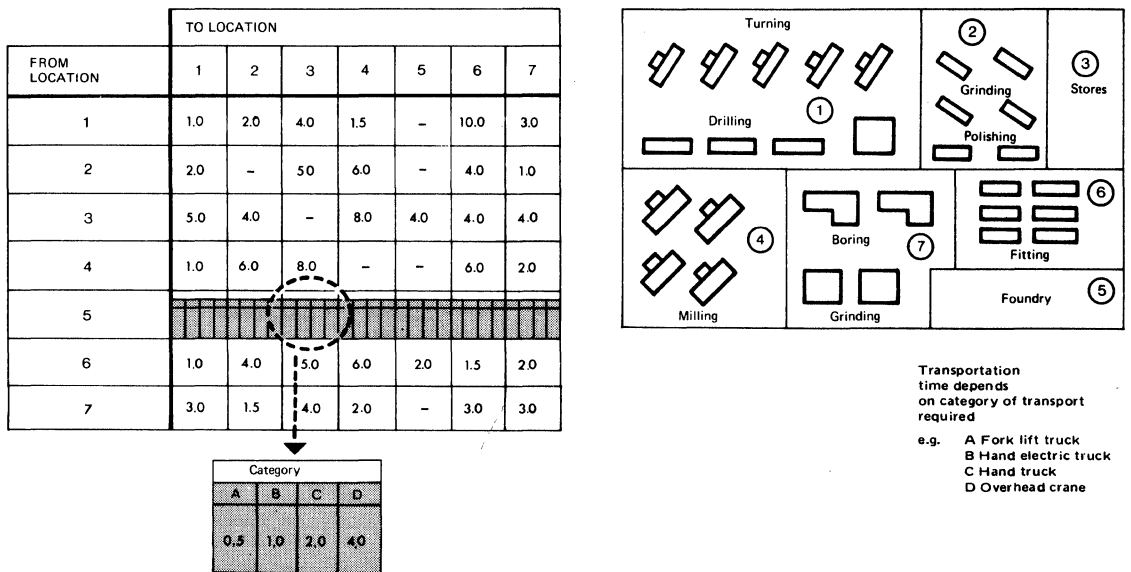


Figure 18. Transport time is expressed in tabular form. The time may vary by type of materials handling equipment normally assigned to the item

When work is normally subcontracted, a location code is associated with the subcontractor, so that a transport time can be allowed.

Location codes should also be given to each warehouse or storage area so that the transportation of material to and from stores can be considered in the schedule.

Special techniques affecting lead time

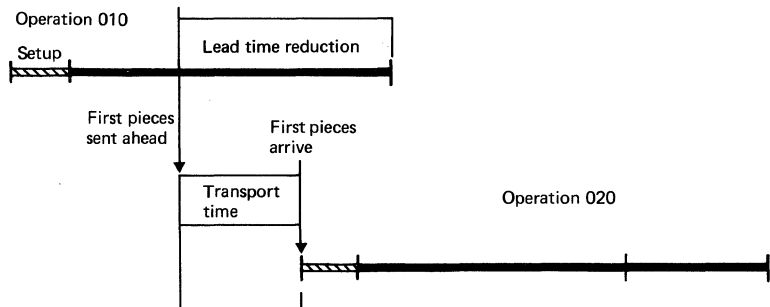
Manufacturing lead times are sometimes affected by:

- Overlapping (starting the next operation before the previous operation has finished)
- Operation splitting (performing one job in parallel on two or more facilities)

Overlapping is a means of reducing lead time (Figure 19). It is also used to relieve congestion at a work center, to utilize idle capacity, or to ensure that the following operation can begin without delay – for example, when the next operation must start within so many minutes of the first operation.

overlapping

- Situation A (Operation 010 < Operation 020)



- Situation B (Operation 010 > Operation 020)

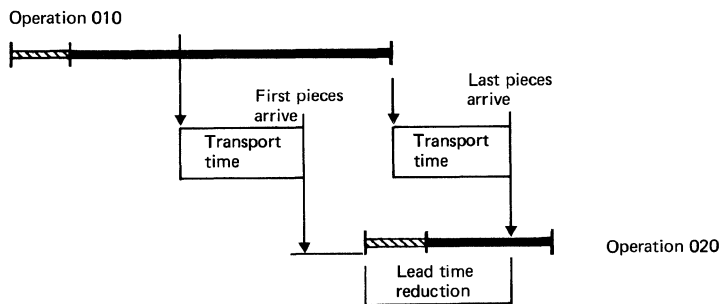


Figure 19. Overlapping is defined as starting the next operation before the previous one has been completed

Overlapping implies that pieces are sent ahead to the next operation before the entire order quantity has been processed. It can be specified in a number of ways — for instance, send ahead when 100 pieces, or one-third of the order quantity, or five hours' work has been completed.

operation splitting

The total manufacturing lead time can also be reduced by performing an operation on several machines in parallel, or by assigning several men to the job (Figure 20). The purpose of this “operation splitting” is to reduce lead time, even though multiple setups result.

Operation splitting may be specified for individual operations whenever the order quantity exceeds a certain value, or the workload exceeds a certain number of hours, or the run time exceeds the setup by a given factor. The criterion is specified by coding in the routing.

Even where operation splitting is desirable, it may not be possible because of unavailability of tools, men, or machines. The system considers the availability of these items when attempting to schedule parallel runs.

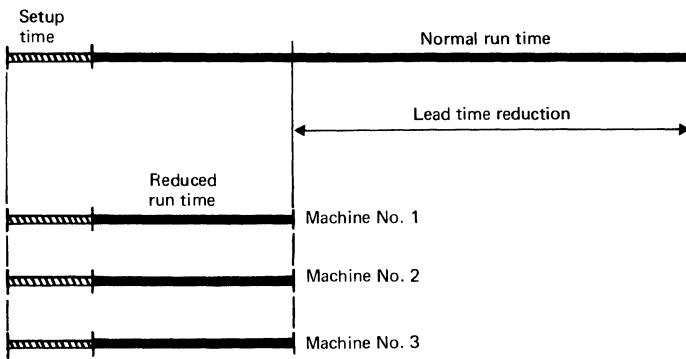


Figure 20. Operation splitting is defined as the performance in parallel of one job on several machines

Overlapping and operation splitting may be designated as standard practice for certain operations; that is, they are always used, irrespective of the situation. On the other hand, they might be coded for use only in “emergency situations”, in an attempt to bring a late order back on schedule. This is discussed in “Rescheduling Orders”.

Calculation of manufacturing lead time

CAPACITY REQUIREMENTS PLANNING maintains records of the lead time information. For each operation in the routing, the following elements are summed:

- Queue time – which varies by work center
- Preparation time – which varies by work center and/or operation
- Setup time
- Run time – which is standard time per item multiplied by average lot size
- Teardown time – which varies by operation
- Postoperation time – which normally varies by work center
- Wait time – which is normally standard but can vary by work center
- Transport time – which is based on a table showing the time between work centers or areas

All these values, and consequently the total lead time, can be considered relatively constant. Once the system is adequately controlled, few changes will be required.

When a lead time is developed through the use of methods discussed above, a *standard* has been established. When deviations, as opposed to permanent changes, from the planned lead time occur, the standard should not be revised.

Calculation of Estimated Start Dates

In its calculation of estimated operation start dates, MANUFACTURING ACTIVITY PLANNING considers all the lead time factors just discussed. Operations are scheduled in relation to the start and finish dates for the order. The system determines the start date for each operation by successively calculating and subtracting the interoperation times and operation duration time (Figure 21). This method of determining start dates is known as “backward scheduling”, since it starts with the due date for the order and determines all other dates by working backward from that date.

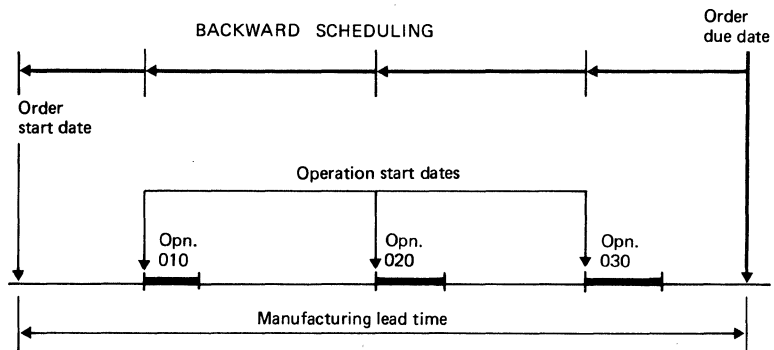


Figure 21. “Backward scheduling” determines the latest start date for each operation

The start date for the order, as designated by INVENTORY MANAGEMENT, is the latest date the order can be released and still be produced on time without compressing the lead time. Thus the calculated dates for both orders and operations represent a schedule that must be observed if all due dates are to be met. The dates are therefore referred to as *latest* start dates. Adherence to the schedule means that all work is performed as late as possible, work-in-process is minimized, the order is finished on time, and there is no unnecessary stock surplus caused by early delivery.

Rescheduling orders

The use of backward scheduling creates one problem that requires special consideration: the rescheduling of orders that have to be completed in less than the normal lead time.

If the time available for delivery is less than the manufacturing lead time for an order, “backward scheduling” yields a start date that falls into the past (Figure 22). This happens, for example, if a customer order is accepted for delivery in less than normal lead time, or if excessive scrap creates a rush order for components.

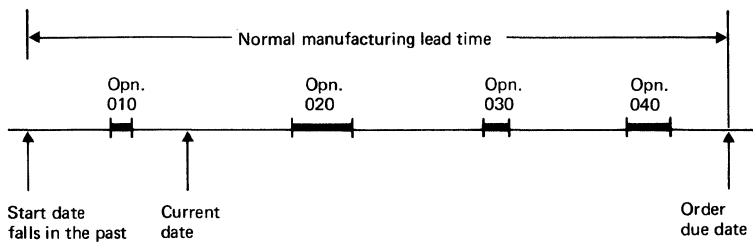


Figure 22. The use of average lead time elements may cause a planned start date to fall into the past

In these cases, either the complete order or individual operations must be rescheduled. The limiting factor is the current date. Expediting can be applied by planning a reduction in lead time. Even then, it may not be possible to achieve the requested due date. This “expediting”, which normally entails additional costs, can be achieved in several ways:

- Reducing interoperation times
- Overlapping and operation splitting
- Lot splitting

One approach to reducing lead time is to reduce planned interoperation times. This, in effect, gives the order a higher priority than jobs without a reduction in interoperation time, allowing it to be scheduled ahead of other jobs in the queue. However, there is a limit to the number of orders that can be so expedited, and a limit to the extent of the possible lead time reduction.

reduction of
interoperation
times

The system can effect the reduction in either of the following ways (Figure 23):

- Reduce interoperation times between the early operations by a maximum percentage in order to restore the order to a normal schedule as soon as possible.
- Reduce all interoperation times for the order by the same percentage (subject to some maximum limit) so that the correction is gradual.

The major amount of reduction is obtained from the queue time and wait time, since the other three elements of interoperation time are fairly fixed.

Even the maximum reduction of all interoperation times may fail to achieve the required result (Figure 24), in which case the following “emergency” measures can be taken in an attempt to maintain the due date.

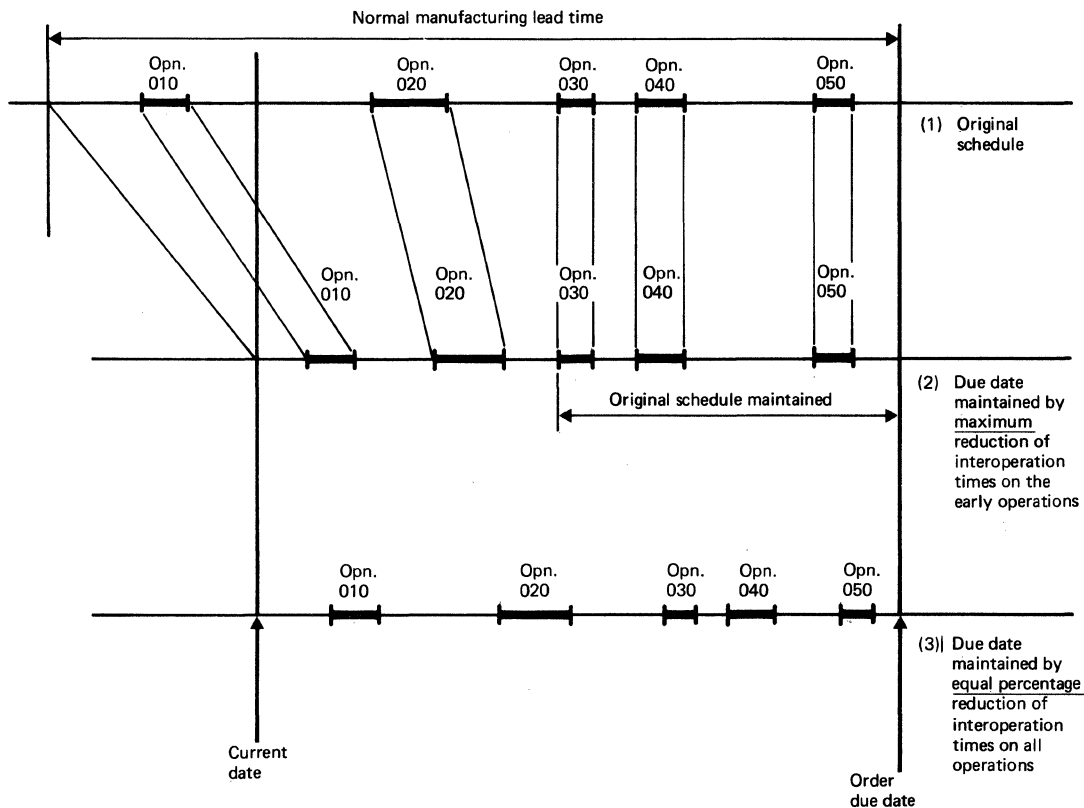


Figure 23. Lead time can be reduced by compressing interoperation time on the early operations, or on all operations

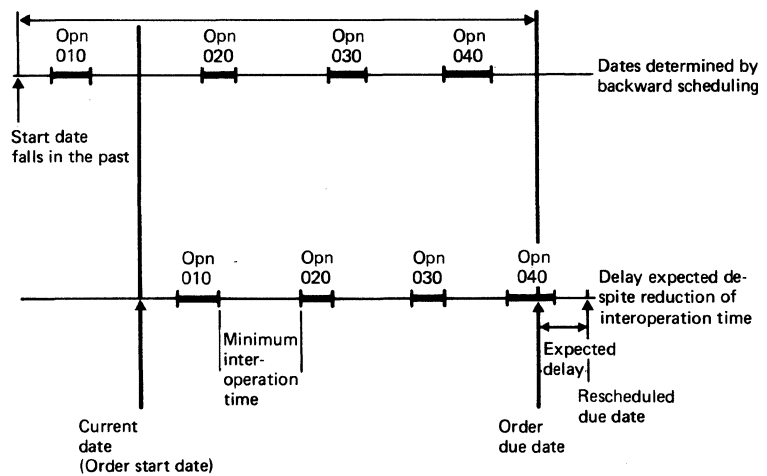


Figure 24. Despite compressing interoperation time, an order may still be late

These methods may be feasible even if not standard practice (Figure 25). The operations concerned are identified by a code in the routing or work center record. The rules may be different from those used to define standard overlapping and operation splitting.

overlapping
and operation
splitting

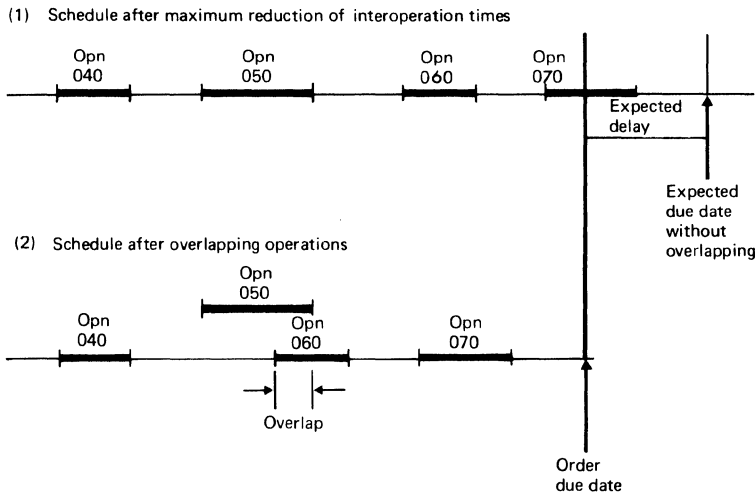


Figure 25. The system may select overlapping in an effort to hold to the original schedule

If the reduction of interoperation times, the overlapping of operations, and operation splitting fail to bring the order back on schedule, the order can be split to reduce the lead time. For example, assume that five pieces are suddenly needed to replace unexpected scrap on assembly (Figure 26) and that an order quantity of 100 is currently in production but cannot be expedited sufficiently. The order quantity of 100 is therefore split into two orders of 5 and 95 respectively, and the 5 are “sent ahead”. The remaining quantity will follow on the original schedule date.

lot
splitting

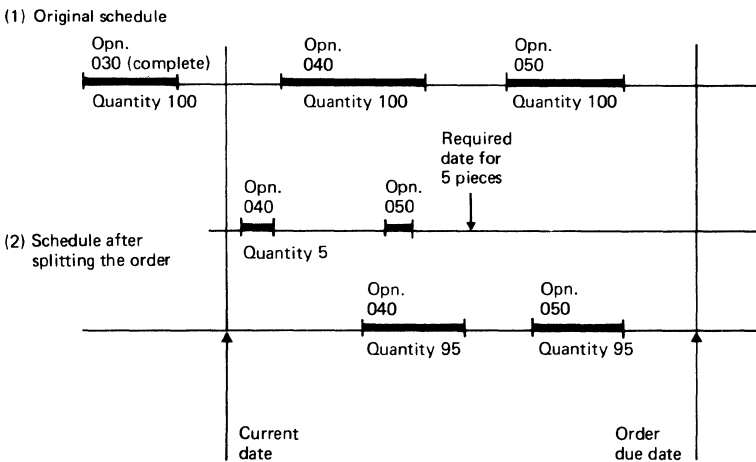


Figure 26. Order splitting can apply as an emergency measure to meet due dates on high-priority orders

Similarly, an assembly order may be split if insufficient components are available to cover the full requirement.

Lot splitting is expensive because it requires multiple setups. Also, since operation duration is normally a small amount of the total lead time, the effect of splitting alone may be minimal.

The rescheduling of operations by any of these techniques is reflected in the load profiles produced by CAPACITY REQUIREMENTS PLANNING.

Delays to an order

After attempting to implement all the scheduling options, it may still be impossible to meet a due date. The rescheduled operation start dates are still later than the dates originally required and the order will probably be delayed.

delays due to
late delivery
of purchased
items

A shop order may be delayed because of late delivery of a purchased component or raw material. The system identifies orders for purchased items, subcontracted items (or operations), interplant items, and raw materials required to complete specific shop orders. The planned start date of a shop order will be affected by any delay of purchased components and will be rescheduled as described earlier.

delays
affecting
purchased
items

The delivery date for a purchased item can be affected by a delay to a related shop order. For instance, two components, one manufactured and one purchased, are required for an assembly. If the shop order for the manufactured component is delayed because of an overload, the delivery date for the purchased component can be delayed by a similar amount.

postponement
of order
start dates

When the system recognizes that a component order will be delayed, it also identifies the affected assembly orders. These orders are traced through the “pegging” information continuously maintained by the system (see *Chapter 5, Inventory Management*). Since the components cannot be made available on schedule, work cannot begin on the assembly orders on their planned start dates. The system therefore modifies these dates in accordance with the estimated component delay. Details of the postponed assembly orders are displayed and other components in process can be rescheduled accordingly.

If the assembly order delay cannot be made up and the end item schedule is affected, the master production schedule should be changed accordingly. MATERIAL REQUIREMENTS PLANNING will then automatically adjust order due dates for all component items affected.

In postponing the assembly orders, the system assumes that the delayed components will not be delivered to stores for subsequent issue to the assembly floor, but will be transported direct to the work center involved (Figure 27). The decision to bypass stores is transmitted to the shop floor via an Action File. Stores is also notified not to expect delivery of the components (see *Chapter 7, Order Release*).

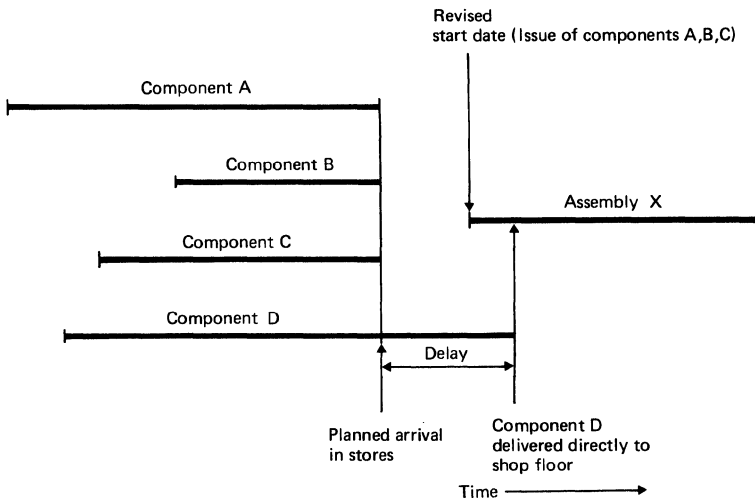


Figure 27. Delayed components can be delivered direct to where they are required, instead of passing through stores

As previously indicated, the system tries to reschedule operations for any order that has insufficient lead time, in order to meet the due date. If the attempt fails, an exception notice is produced, showing the expected delay (Figure 28).

delayed
order
report

If the order is for a component used in a number of assemblies, the system can produce, on request, a list of all assembly orders using that component.

A delay to a component order normally causes the postponement of the assembly order(s) for which the components were produced or purchased. The system calculates revised start dates automatically. The Delayed Order Report (Figure 28) shows which component (if any) has caused the postponement. In the illustration, the order for item 107253 is to be released 15 days late because component 85327 has been delayed.

forced
release of
assembly
orders

On occasion, the inventory administrator may decide to override such a decision. Postponement of the assembly order is not necessary if the short items can be introduced at a later stage. Late introduction of parts is normally inconvenient and costly, but may be preferable to postponement of the whole order.

CURRENT DATE 480

D E L A Y E D _ O R D E R _ R E P O R T

PRODUCT	DESCRIPTION	QTY	START DATE	DUE DATE	DAYS BEHIND SCHEDULE	OPERATIONS REMAINING	POSSIBLE LEAD TIME REDUCTION	EXPECTED DELAY (DAYS)	REASON FOR DELAY
073246	CRANK SHAFT	100	473	490	6	2	3	3	NO TOOL
107253	GEAR BOX	1000	451	470	15	1	2	13	PART 85327
310442	RATCHET	800	470	482	8	4	5	3	MACHINE DOWN
437127	GEAR	200	490	510	20	12	6	14	EXCESS SCRAP
440258	GEAR	50	510	540	14	20	10	4	EXCESS SCRAP

Figure 28. All orders that will be delayed despite the system's special rescheduling procedures are indicated on an exception report

If the inventory administrator decides that an assembly order should be released on the planned date despite missing components, the system is notified and the previous decision is reversed. The order is released on the original planned date. In such cases of "forced release", the delayed components are transported to the shop floor as soon as available.

Determining Capacity Requirements

Because of all the changes that occur in the manufacturing environment it is reasonably certain that any planned operation start date calculated in advance will not be valid weeks or months later. However, to get more than just a general feeling of the capacity requirements, it is necessary (and using a computer, simple) to calculate the operation start dates (and hence the completion dates) reasonably accurately.

What, then, *can* be determined ahead of time with a fair amount of reliability is the *range* of operation start dates (Figure 29):

- The *latest* date by which an operation must be started in order to meet the due date of the order
- The *earliest* date it is possible to start an operation because of, say, material availability

It is not known on which day the operation will actually be performed, but it is probable that it will be between these two dates. The actual date will depend on a number of factors, such as completion of the previous operation, tool availability, priority, capacity availability, amount of idle time, etc.

Determining a *realistic* planned start date for the operations will be discussed in “Order Release Planning”.

CAPACITY REQUIREMENTS PLANNING schedules every operation on every order and reschedules those with inadequate lead time. The calculated operation dates determine when the load is likely to occur on each work center. This information can be displayed as a load profile (Figures 30A – 30C).

Each profile shows the capacity required, based on the assumption that every job is done as late as possible while order due dates are met. The typical profile is highly variable.

This type of report shows where and when additional capacity is required to meet the workloads. Furthermore, the cumulative load over all periods can be compared to the cumulative capacity, to determine whether the capacity is adequate *on the average*. In Figure 30A the total load is 560 hours and the total capacity 700, indicating that the work center is underloaded. There may be overload situations in periods 2, 5, 6, and 7, unless some adjustments are made. How can adjustments be made to avoid this situation?

There are two possibilities. Either the capacity must be modified period by period, so as to exactly balance capacity with the load, or some of the load must be moved into the underloaded periods.

The first of these alternatives, constantly modifying capacity, is not easy to achieve. It demands fluctuations in the labor force. Even if this were feasible, it would not ensure perfect balance between loads and capacities, because of the inaccuracies inherent in load calculation and the fluctuating performance and availability of the labor force.

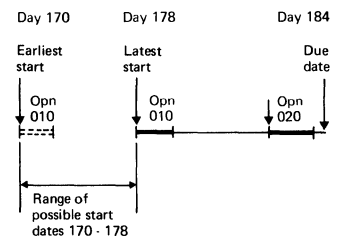


Figure 29. The range of start dates for an operation is determined

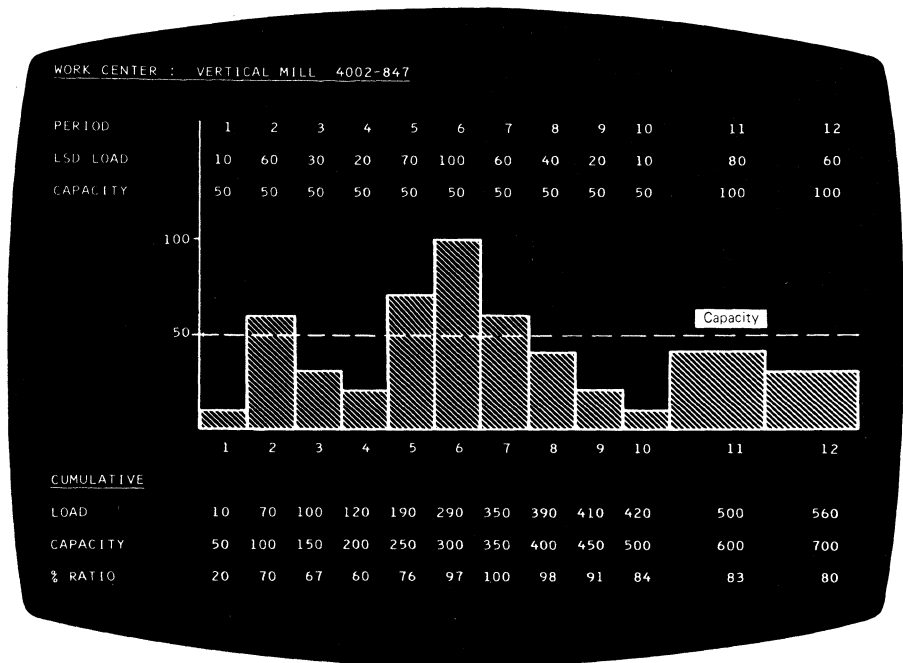


Figure 30A. A load profile shows where overloads and underloads can be expected

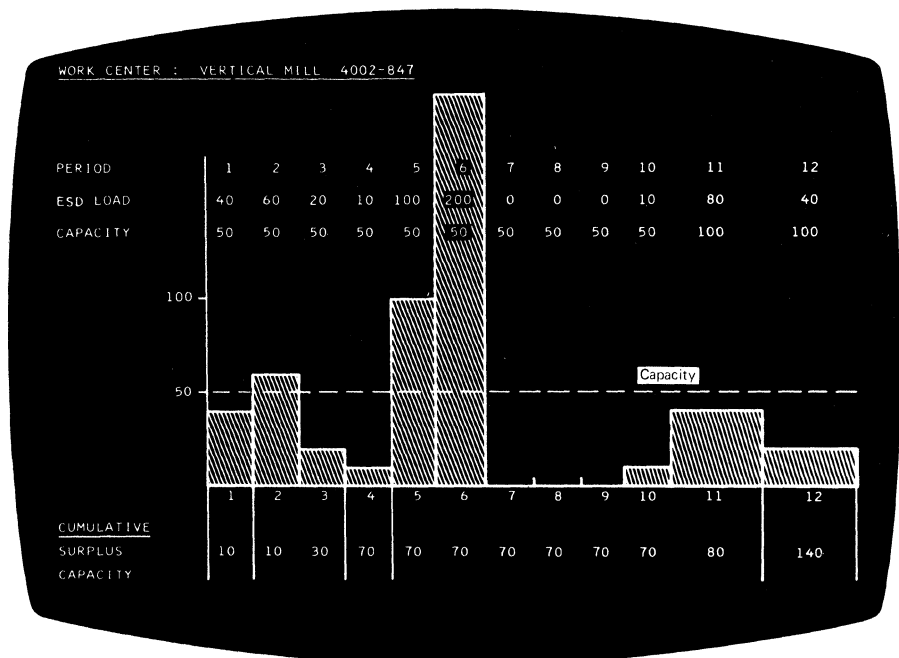


Figure 30B. A load profile based on the earliest possible start date indicates where surplus capacity will exist if all work is moved as early as possible

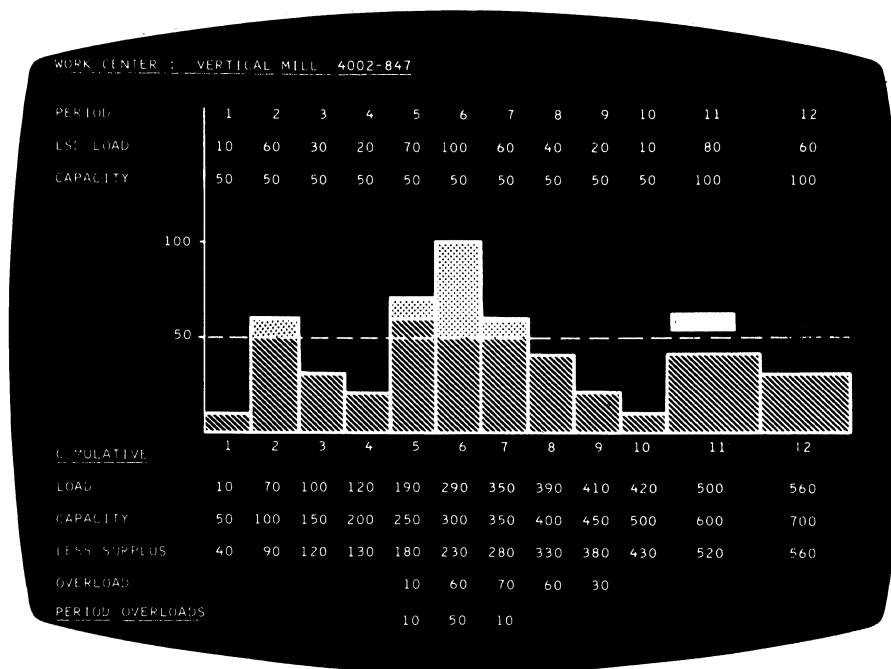


Figure 30C. Unresolved overloads remain after removing “unusable” capacity

The second alternative, moving the load, is more acceptable because it allows capacity to remain reasonably stable; that is, it allows the workload to be leveled in accordance with the capacity. The procedure is therefore known as “load leveling” or capacity stabilization. However, the less stable the environment the less effective this approach will be.

Capacity stabilization

Figure 31 shows a different situation where the normal capacity of the work center is too small to meet the load.

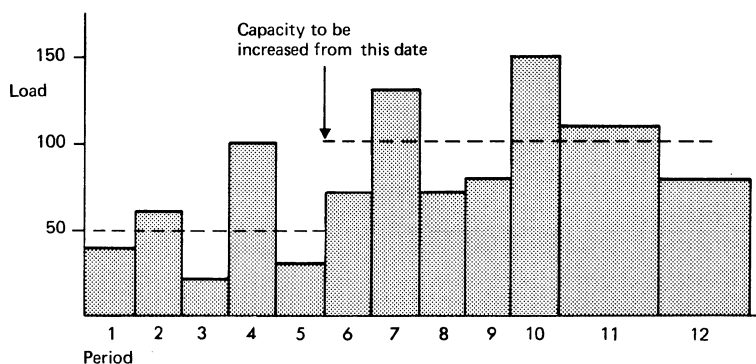


Figure 31. This load profile indicates a need for a capacity increase starting in period 6

A decision is necessary which may be to work a second shift from period 6 onward. The decision is entered in the system by altering the designated work center capacity for periods 6 – 13. The system responds with a confirmation that the cumulative capacity is now adequate. As in the previous example, there are still several impending overloads (periods 2, 4, 7, 10, 11, and 13) but the assumption at this point is that these load problems can be resolved by doing some work early. Here it is assumed to be preferable to reschedule operations rather than make frequent short-term capacity changes. In the example, capacity is stabilized at the original level over the first five periods, and at the higher level after that.

However, the success of the plan depends on the assumption that certain jobs can be performed ahead of schedule. CAPACITY REQUIREMENTS PLANNING determines whether this is possible. If it is *not* possible, some overload situations will remain and there will be capacity surpluses in earlier periods. CAPACITY REQUIREMENTS PLANNING identifies the problem periods for further management action.

restrictions
on starting
early

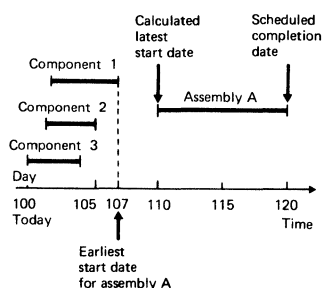


Figure 32. An order cannot be started before all its components are available

Basically, then, load leveling is achieved by doing certain operations ahead of schedule. But *how far* ahead of schedule? How *early* can they be performed? What restrictions are imposed, either by the situation on the shop floor or by management policy? In answering these questions the following factors must be considered:

- Inability to move the scheduled start date earlier than the *availability* date of necessary manufactured and purchased components, raw materials, and tools. Figure 32 shows the scheduled delivery of three components for assembly A. The earliest date the assembly could be started because of material restrictions is day 107. If component “1” could be improved, the earliest date would be 105.
- Inability to move operations for fabricated components and assemblies earlier than the scheduled finish date of the previous operation in the routing.
- The *maximum allowable advance* specified by management. For example, no operation should be performed more than ten days in advance of the original schedule.

The last of these restraints reflects the importance placed by management on maintaining stable capacity. A large allowable advance results in the early completion of work, causing either excess component inventory (if all operations for an order are advanced) or increased work-in-process (if only the earlier ones are advanced).

The allowable advance should therefore vary with the value of the items. It should also be adjusted according to the variability of the load profiles; if loads are generally constant, only small advances are necessary, and the allowance should be kept small.

CAPACITY REQUIREMENTS PLANNING determines to what extent *load leveling* is feasible. It achieves this by determining the earliest possible start date, considering these restraints for every operation yet to be performed, and accumulating a load profile based on the earliest start dates. It is then possible to calculate the underloads or surplus capacity that will persist despite all attempts to perform work early.

In an unstable environment, capacities can only be planned to match *average* work center loads over multiple periods. The main emphasis then must be on maintaining the planned *rates* of output, and on keeping relative priorities valid at all times.

Surplus capacity (underloads)

Period 1 of the load profile in Figure 30B shows a load of 40 hours and a capacity of 50 hours. This implies that even if all jobs were done as early as possible (subject to the restraints discussed), there would be a surplus capacity of 10 hours at this work center; that is, the facility would lie idle for at least 10 hours during the shifts planned for that period. Similarly, if periods 1, 2, and 3 were considered together, the total workload (120 hours) would be less than the available capacity (150 hours). Over these periods, therefore, the machine would lie idle for at least 30 hours. The surplus capacity is similarly calculated for every period across the planning horizon.

This information provides management with the opportunity to reduce idle time. Men can be transferred to relieve overloaded centers. Alternatively, the “allowable advance” previously discussed can be increased, and work can be performed early to absorb the surplus capacity.

The sequence of events up to this point is:

- CAPACITY REQUIREMENTS PLANNING produces a load profile for each work center, based on working to the latest start date.
- Capacities are adjusted, if necessary and possible, to ensure that they are at least adequate *on the average*. Stable capacity is normally planned.
- CAPACITY REQUIREMENTS PLANNING identifies any capacity surpluses, by accumulating “earliest start date” loads.

- If the surpluses are unacceptable, capacity is reduced accordingly. This usually means working shorter hours or transferring labor. Alternatively, the values for “maximum allowable advance” can be increased, to give more freedom to perform work early. The earliest start date load is then recalculated.

Capacity shortage (overloads)

By this stage, an approximate balance between loads and capacities has been achieved. On occasion, however, it will prove impossible to provide the necessary capacity at a work center; required skilled labor is not available, or the load is too large to be resolved within the time frame allowed.

Accordingly, CAPACITY REQUIREMENTS PLANNING identifies any unresolved overload situations (capacity shortages). It does this by comparing the total load against the total capacity. In Figure 30C the total load over periods 1 to 5 (190 hours) exceeds the total capacity (180 hours). No matter what attempts are made to level the loads (by performing work ahead of schedule), a surplus load of ten hours' work will accumulate over these periods. Note that the values for capacity are reduced by the “surplus capacity” figures previously calculated; it has been established that under the quoted “maximum allowable advance” restriction no use can be made of these surpluses (unless, of course, additional orders are accepted).

These profiles thus provide management with advance information of unresolved overloads. It may still be possible to resolve these overloads by revising earlier decisions regarding capacity levels or the “maximum allowable advance” restriction. If it is not possible, some delayed orders can be expected. The orders that will probably be delayed are determined in ORDER RELEASE PLANNING.

Other alternatives include subcontracting certain orders or operations, “offloading” the work to another plant, or using alternative methods of manufacture within the same plant.

Using alternate work centers to resolve capacity problems

The most convenient way to resolve overloads is to do some operations at alternate work centers within the plant (see “Alternate Work Centers”). This may increase the job cost (for instance, performing work on less efficient equipment), but it is usually preferable to having the work done at some other location.

This “rerouting” is desirable only if the alternate work center has *surplus* capacity at the time the overload develops at the original work center. Sending work from the original center to the alternate can then solve two problems simultaneously — the overload at the original center and the underload at the alternate.

CAPACITY REQUIREMENTS PLANNING attempts to match surplus capacity at underloaded work centers with capacity shortages at overloaded centers.

Load and capacity are being considered on a *cumulative* basis without any operation dates actually being changed. At this stage it is not possible, nor is it necessary, to estimate exactly when the surplus capacity will be available, or how large it will be in any particular period. The situation is almost sure to change before the decision to reroute the order is made. Firm decisions are eventually made by the operation sequencer when the exact details of the situation are known.

However, if a cumulative surplus matches a predicted overload, the system assumes that the overload can be resolved in ORDER RELEASE PLANNING — in other words, that ORDER RELEASE PLANNING will plan to make use of a surplus at the alternate work center whenever it happens to be idle, thus resolving the overload.

When an overload can probably be prevented by using an alternate work center, this is indicated on the load profile, and the planner does not have to take any action.

Load Analysis

If a *capacity shortage* (overload) cannot be resolved either by advancing work or using alternate work centers, a further possibility is to subcontract certain operations or orders. This is usually more expensive than manufacturing the items in the plant, but is preferable to having orders completed behind schedule. The system can identify the specific operations or orders that should be offloaded in order to preserve the balance between load and capacity. The choice is based on several criteria (see “Overload Analysis”).

Any remaining *surplus capacity* (idle time) can be reduced either by transferring labor to other work centers or by working shorter hours. Another possibility is to accept extra work, which means either producing items for stock prematurely, or processing subcontracted orders for other plants. If several tentative orders compete for the surplus capacity, the system can identify the most acceptable (see “Underload Analysis”).

Overload analysis

Overload analysis determines which orders or operations should be offloaded from a work center so as to resolve an overload in a particular period.

Attention is given first to “critical” work centers that have an unresolved overload, because their output affects the output of the entire plant.

In deciding which operations to offload, several factors are considered:

- Operation duration. It is usually preferable to subcontract one long operation instead of several short ones.
- Subcontractability. Tool availability or machine type might preclude manufacture in any other location, as would the time available to shift the orders to the subcontractor and back again.
- Subcontracting cost. In many cases, an operation cannot be subcontracted by itself, and the entire order must be offloaded. For each order that is a candidate for subcontracting, the system can calculate the extra cost involved, considering all operations.

The system can thus identify the order or orders that could be subcontracted at the smallest extra cost.

It may be convenient to subcontract a complete “network” of interrelated orders, representing several levels of production for one end item order. The extra cost of subcontracting the network is calculated by the same method.

The system provides all this information on request (Figure 33), and the planner chooses the order(s) to be offloaded. The system then *simulates* the effect of the decision, showing the new load profiles on the terminal. Several tentative decisions may be simulated before final decision is reached.

Underload analysis

If a capacity surplus (underload) cannot be reduced to an acceptable level, either by transferring labor or working shorter hours, then additional work must be found to occupy the labor force.

The problem is to identify orders that would absorb the surplus capacity without causing problems at other work centers. In general, an order is not acceptable if it causes any work center to be loaded above maximum capacity. The system can determine whether this is the case for any specified order.

WORK CENTER: VERTICAL MILL 4002-847
 DATE: 901 - 906
 CAPACITY: 50 HOURS (NORMAL) 60 HOURS (MAXIMUM)
 LOAD: 75 HOURS
 POSSIBLE OFFLOAD TO EARLIER PERIODS: 5 HOURS
 UNRESOLVED OVERLOAD: 10 HOURS (MINIMUM)

LOAD ANALYSIS

ORDER NO.	ITEM NO.	ORDER DATE	QTY.	OPN.	HOURS LOAD	SUBCONTRACT POSSIBLE?	EXTRA COST
20751	112564	872	500	040	15.0	YES	320
20824	260930	880	1000	070	7.2	YES	400
31974	020741	894	650	020	22.3	NO	-
22010	512282	884	200	030	15.6	YES	755

Figure 33. Overload analysis indicates the best candidates for subcontracting

If an order is acceptable, the system can also use the cost curves already discussed to determine the labor cost involved in producing the order. If the order is to be subcontracted, the price asked for the work can be compared against this estimated labor cost, to determine the profit for the job.

Another alternative to resolving underloads is to change the release dates of planned orders already on the order file, and produce them well ahead of schedule. (This implies that the “maximum allowable advance” restriction can be overridden for individual orders and that raw material will be available.)

The function of the planner is to specify the item number, due date, and quantity for each proposed subcontracting job, or the item number plus due dates (original and proposed) for any planned order that is a likely candidate for production ahead of schedule. The system then provides the cost comparisons.

The technique of Underload Analysis is also used whenever a customer requests short-term delivery of an order (see “Trial Fitting of Orders”).

Using the System

CAPACITY REQUIREMENTS PLANNING provides management with advance information about capacity requirements, enabling them to foresee potential bottlenecks and idle time. A balance between capacities and loads can then be planned, minimizing last minute emergency action. A balance of capacity to load is needed if the objectives of on-time delivery and minimum idle time are to be simultaneously obtained. If capacity is too small, late orders will result; if capacity is too large, idle time will be the price of on-time delivery. The objective of CAPACITY REQUIREMENTS PLANNING is to determine required rates of output by work center and to balance as closely as possible the available capacity with the requirements.

Continuous review

CAPACITY REQUIREMENTS PLANNING is not a periodic planning system. It maintains, hour by hour, all relevant information on both loads and capacities. Loads in particular are constantly changing, as a result of net changes from INVENTORY MANAGEMENT. Whenever a change is made, the system analyzes each affected work center load profile, and detects any of the following situations:

- Cumulative capacity (planned rate of output) over a period of time inadequate to meet the load
- Considerable shortage of capacity (overloads) in particular periods
- Excessive surplus capacity (underloads) in particular periods

Whenever any of these conditions are serious enough, that is, when certain specified limits are exceeded, the planner is notified via an Action File. Figures 34A and 34B represent a problem situation. The asterisks, which represent different degrees of overload, show where the system has detected a problem.

Management can react to the situation in one of three ways:

- Ignore the warning and accept the consequences. For instance, in the case of underloads, surplus capacity may be allowed because additional customer orders are expected.
- Adjust loads, using the techniques described under "Load Analysis". If an order is offloaded, the loads it represents are removed from the load profiles concerned.
- Increase capacities by planning overtime or extra shifts, or by transferring labor; or decrease them by transferring labor or working shorter hours. Decisions to modify capacities are entered by terminal into the system, which confirms that the change has had the desired effect when it displays the new situation (Figure 34B).

WORK CENTER : TURRET LATHE 4100-300

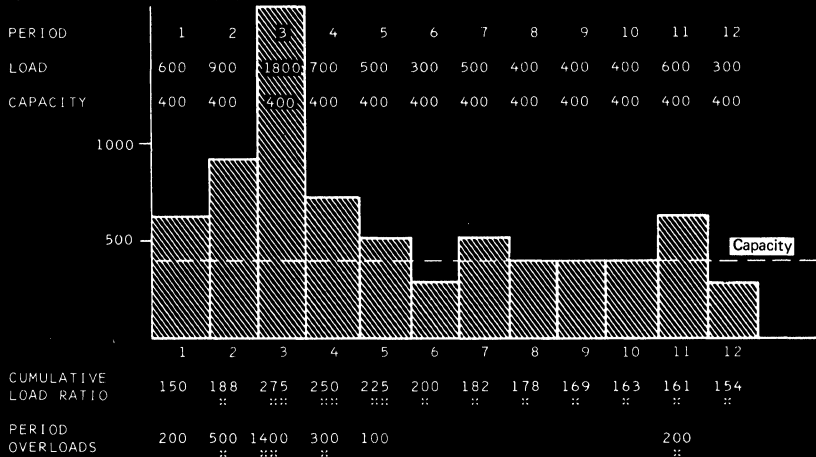


Figure 34A. The planner reviews exception situations caused by changes in load

WORK CENTER : TURRET LATHE 4100-300

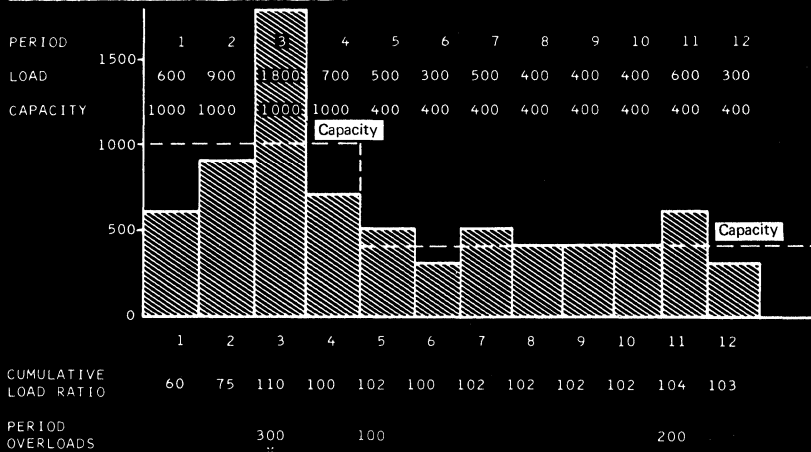


Figure 34B. After the planner makes an alteration to the capacity level, the system responds with an immediate reanalysis of the load and capacity comparison.

Minor overloads may have been allowed to persist because it is known that some overtime work can be arranged at short notice. Several tentative decisions may be simulated before the final one is reached.

In specifying a capacity change, the planner provides the following information:

1. Work center identification number
2. The increase (or decrease) in the capacity. He can specify the number of men, machines, or shift hours, and the system will make the adjustment for normal efficiency, losses, etc.
3. Dates for which the changes are "effective from" and "effective to"

By this procedure, the balancing of loads against capacities is kept under constant review. The system resummaries the total manpower load by period for all work centers as capacity changes are made to individual centers. In this way, the planner can confirm that his capacity decisions are feasible in terms of additional manpower.

While CAPACITY REQUIREMENTS PLANNING is used primarily to determine what capacities will be needed to meet the planned workload, PLANT MONITORING AND CONTROL measures the actual output by work center. Management should be informed if actual output lags behind the rate that has been planned, and should take appropriate action to restore the balance.

Additional reports

For an individual work center that has a load problem, the detailed load report shown in Figure 35 can be printed. The information is identical to the reports displayed earlier, but here it is consolidated into one report.

In this report, as with the earlier displays, the load for a specific work center or individual machine can be printed in any combination of:

- Machine hours (with or without setup hours)
- Labor hours (with or without setup hours)
- Setup and teardown time

Also shown is how much of the load it is possible to transfer to or from alternate work centers.

- (+) indicates overloads on other work centers which can be transferred to this work center to fill up idle time.
- (-) Indicates overloads on this work center which can be transferred to alternate work centers.

CAPACITY REQUIREMENTS PLANNING REPORT																	DATE 881 PAGE 180									
WORK CENTER - VERTICAL MILL 4002-847										ALTERNATE WC NO'S 4002-731 4002-899 4003-151 4001-100 2003-467																
NO.	PERIOD START	LENGTH DAYS	AVAIL		ESD HRS	LSD HRS (*)	ALT HRS (+/-)	0	100	PERCENT		UNDERLOAD		0	50	PERCENT		OVERLOAD		0	50	PERCENT		SET UP ESD HRS	LOAD LSD HRS	
			CAP HRS	HRS						200	NONU HRS (*)	TOTAL HRS (+)	100			UNAV HRS (*)	CUM HRS (+)	100	ESD HRS			LSD HRS				
1	881	2	20	15	0	+15	.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10	0	
2	883	2	20	15	0		.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	8	0	
3	885	2	20	20	10	+10	.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	7	5	
4	887	2	20	30	20		.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	10	
5	889	2	20	20	30		.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	5	5	
6	891	5	50	20	30		.++++++	.	.	5	5	.xx	.	.	.	.	.	.	.	.	.	.	.	10	10	
7	896	5	50	10	20	+20	.++++++	.	.	20	20	.++++++	.	.	.	.	.	.	.	.	.	.	.	5	10	
8	901	5	50	100	70		.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	50	40	
9	906	5	50	200	100	-40	.++++++	.	.	.	.	.	.	.	.	.	10	10	.xxxx	.	.	.	.	90	50	
10	911	5	50	0	60		.++++++	.	.	.	.	.	.	.	.	.	10	20	.++++++	.	.	.	.	0	30	
11	916	5	50	0	40		.++++++	.	.	.	.	.	.	.	.	.	.	10	.++++	.	.	.	.	0	15	
12	921	5	50	0	20	+20	.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	0	10	
13	926	5	50	0	10	+15	.+++++	.	.	5	25	.++++++	.	.	.	.	.	.	.	.	.	.	.	0	0	
14	931	10	100	80	80		.++++++	.	.	20	20	.xxxx	.	.	.	.	.	.	.	.	.	.	.	35	20	
15	941	10	100	40	60		.++++++	.	.	60	60	.++++++	.	.	.	.	.	.	.	.	.	.	.	20	30	
16	951	10	120	120	110		.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	30	10	
17	961	10	90	80	40	+50	.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	10	20	
18	971	20	200	160	200		.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	85	100	
19	991	20	200	150	130	+25	.+++++	.	.	25	25	.xxxx	.	.	.	.	.	.	.	.	.	.	.	70	65	
20	11	20	200	210	190		.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	110	80	
21	31	20	300	340	260	+30	.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	180	150	
22	51	20	150	260	190		.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	150	100	
23	71	40	400	200	130	+270	.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	90	60	
24	111	40	420	200	200		.++++++	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	95	95	
25	151	40	400	100	200		.+++++	.	.	260	260	.++++++	.	.	.	.	.	.	.	.	.	.	.	50	110	
TOTALS			310		2370					395						20							1115			
				3180		2200					415						40							1025		
Legend																										
PERIOD			— Period number																							
START			— Start date of period																							
LENGTH			— Period length in days																							
AVAIL CAP HRS			— Available capacity in this period (hours)																							
ESD LOAD HRS			— Load hours based on Earliest Start Dates																							
LSD LOAD HRS			— Load hours based on Latest Start Dates																							
ALT LOAD HRS			— Load which can be taken from excess loads at alternate work centers (+) or offloaded from this work center into surplus capacity at other work centers (-).																							
TOTAL UNDERLOAD			— Surplus capacity based on planned ESD load																							
NONU UNDERLOAD			— Surplus capacity considering alternate work available from other work centers																							
UNAV OVERLOAD			— Unavoidable overload, assuming overloads in previous periods have been resolved																							
CUM OVERLOAD			— Cumulative unavoidable overload, i.e. difference between cumulative load and cumulative capacity up to and including this period																							
SET UP LOAD			— Set-up load hours in each period based on ESD and LSD start dates																							

Figure 35. The detailed load report can be printed when discussion is needed to solve remaining load problems.

The alternate work centers (in order of preference) are listed at the top of the report.

Daily reports are prepared for plant management to help them implement the planned capacity alterations (Figure 36). These reports summarize the necessary movement of men between work centers.

MANPOWER SHIFT PLAN				
DATE	WORK CENTER	CHANGE HOURS	CHANGE LENGTH IN PERIODS	MANPOWER CHANGE
104	172	+ 16	4	+ 2
	274	+ 24	1	OVERTIME
	279	- 20	3	- 2
	644	+ 8	6	+ 1
	692	+ 16	4	+ 1
105	109	- 20	4	- 3
	612	+ 8	5	+ 1

Figure 36. Capacity changes affecting manpower are summarized daily to help plant management implement changes

Trial fitting of orders

In custom manufacturing, the techniques of Earliest Start Date Analysis are used whenever a customer requests short-term delivery of an order. Material availability is checked in INVENTORY MANAGEMENT. The workloads involved are determined by CAPACITY REQUIREMENTS PLANNING. The analysis then reveals the effect of the new order on the load profiles.

The system issues a warning if the new order causes any work center load to exceed maximum capacity. Otherwise it calculates the labor costs involved in producing the order.

Individual load profiles can be studied before the order is accepted. The system displays these for analysis (Figure 37). The planner may decide to adjust capacities and accept the order, or not accept the order because of unresolvable load problems.

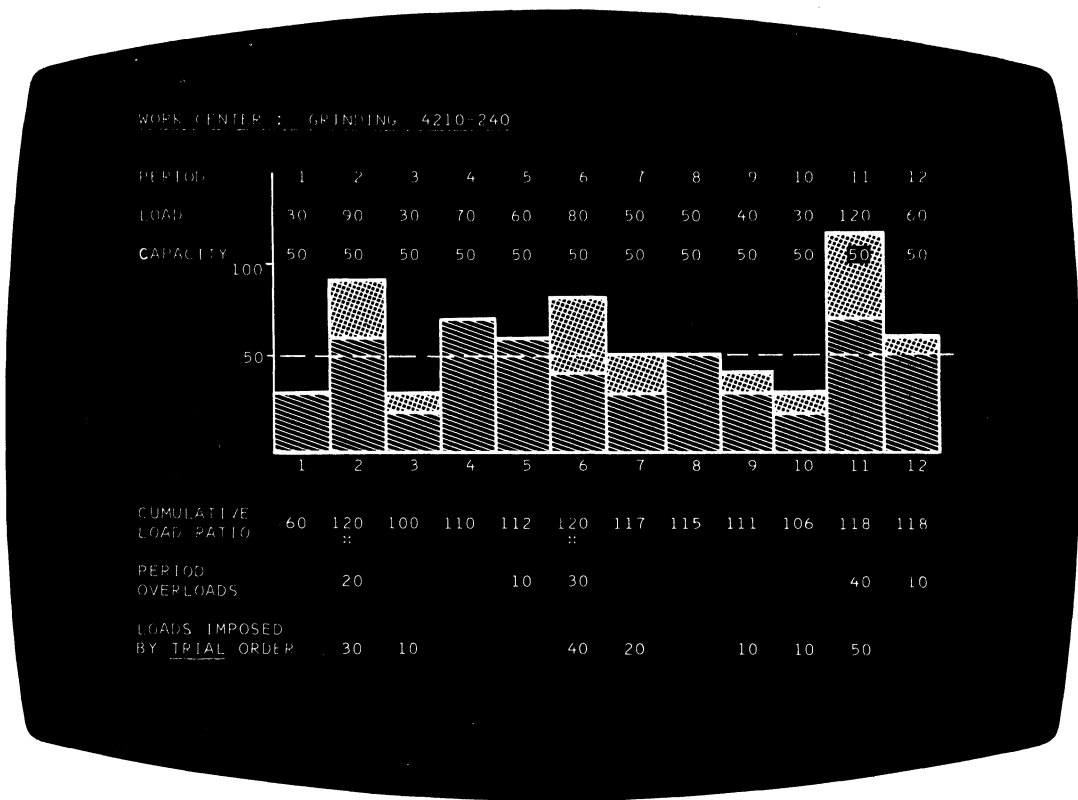


Figure 37. Example of how a system can display overloads caused by an order accepted within normal lead time

Priorities

priorities in
manual
systems

Shop Order No.		Date issued		Item No.	
TG6610		207		A43792	
Description					
M. S. SHAFT					
Card	Contract No.	Plant	Quantity	Stock Date	Ordered on
1	278	E	20	23/	JAMES
Material Description					
1 OF 22 1/2 x 3/8" OD M.S.B. SH.					
1. FEED TO STOP CENTER 2.15 DRILL & CHAMFER TURN 0.25 DIA. AND PART OFF.					
2. COUNTERBORE & TAP 3/16"					
3. INSPECT					
4. FINISH: PROCEED TO 100					
5. INSPECT					
6. STORE					
TOP PRIORITY					
WEEK 42					
J Sm					

Figure 38. Priority systems get out of hand if they are not controlled

priority
systems on
the computer

For a variety of reasons, some orders, and therefore some operations, are more important than others. These orders carry a higher priority. Every plant has a system for identifying high-priority jobs that are allowed to move ahead of other jobs in the work queue.

In a manual system the priority rating given to a job is often a *static* value given to the order on release. It does not reflect the changing conditions in production. Furthermore, the priority rating is based on rather simple criteria.

The order due date is obviously an important factor in determining priority. Usually the date by which the order should be completed is shown on the routing or job card. Perhaps the cards have different colors denoting the urgency of the situation – say, buff for “normal” jobs, yellow for jobs required within the week, red for those required “immediately”. Obviously the system can work only if the number of red and yellow cards is very limited.

Because that is hardly ever the case, another priority system has to be superimposed: cards are stamped “rush”, or “urgent”, etc. (Figure 38).

Eventually all these distinctions lose their significance, and the foreman has to rely on the expeditor or on his own judgment in recognizing the important jobs. Usually his decisions are based on insufficient facts.

Many systems rely on “shortage lists”. In these cases the foreman may have to decide which shortage list has the highest priority.

Sometimes computers are used only to provide bigger and better shortage lists showing what went wrong with the production plan – but showing it after the damage is done. Management then has to take appropriate emergency action.

The computer should be used for better planning, so it can help correct problem situations before they get out of hand. It can reschedule delayed operations. It can recommend the best sequence in which to run jobs. It can schedule every operation in the plant according to the latest order due dates and priority rules established by management. In doing this, it helps achieve the following improvements:

- Successful operation of the priority system no longer depends entirely on the judgment of the foreman and the expeditor.

- Manual expediting is reduced considerably — fewer “stock chasers” are needed to find and push individual jobs.
- The time spent in production meetings to discuss scheduling problems is greatly reduced.

Two levels of priority. Priority calculations are necessary in both ORDER RELEASE PLANNING and OPERATION SEQUENCING.

Order priorities are considered in both systems; operation priorities only in OPERATION SEQUENCING.

- Order priority is a measure of the importance of an order relative to others. “Order” here means either a shop order for a single item, or a whole “network” of shop orders representing a customer order or contract (say, for a generator or power station). A network is illustrated in Figure 39.
- Operation priority determines which of the jobs in queue should be done next; it is based on the priority of the order, in combination with factors such as:

The on-schedule position of the job

The situation at the work center to which the next operation is routed

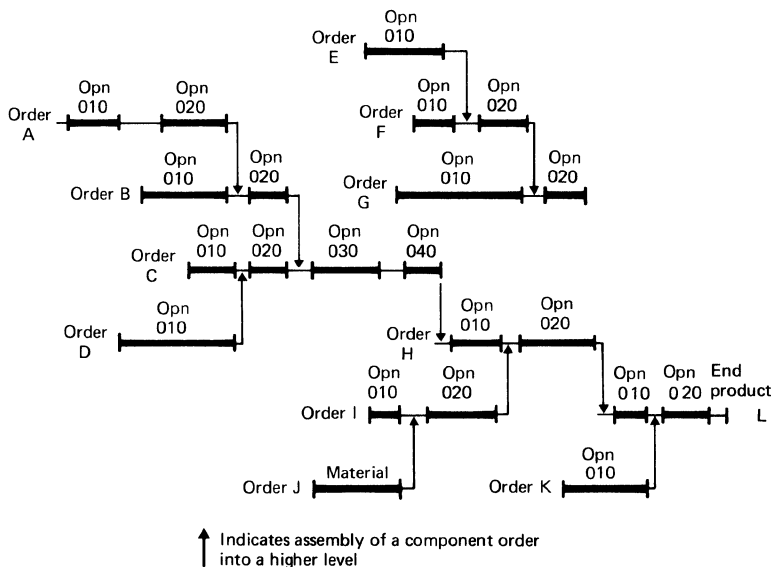


Figure 39. A “network” of orders describes how lower-level component and subassembly orders are related to the building of an end product order

Basis of order priority

The primary basis of order priority is the order due date. Assuming that order due dates are kept valid, there is no need for other order priority criteria, as long as the due dates can be met. If, however, all of the order due dates cannot be met, or if it is uncertain whether they can be met, other factors can be considered to establish relative order priorities.

end item
order
priorities

Depending on the type of industry, different factors will determine end item order, or customer contract, priorities. In “custom” manufacturing, for instance, management may establish general order priorities based on factors such as:

- Customer importance
- Penalty-clause contracts
- Size of the order

In many manufacturing industries, the source and the type of end item order will determine relative order priority. For example:

- In the automotive industry, a customer (retail) order is given priority over dealer or company warehouse orders.
- In the machine tool industry, an order for a machine will have priority over an order for an attachment. In this case, the basis of the priority is the revenue and profit contribution of the order.

These management-imposed priorities (sometimes called “external” priorities) pertain to the customer order or contract and, by extension, to the whole “network” of component shop orders generated to produce the end item.

shop
order
priorities

The shop order priority is governed by its due date. In a plant making an assembled product, the overwhelming objective is to get *all* the parts to the assembly floor on time. Here the major problem is to *maintain the validity* of due dates on all open shop orders. Order due dates, as originally determined, correspond to the planned date of need. This date of need, however, often changes after the order is released as a result of changes in the production schedule. Some orders prove to be needed earlier, and some later, than originally planned.

INVENTORY MANAGEMENT (see Chapter 5), through its material requirements planning function, provides the capability of continuous open order due date reevaluation and adjustment. This system, if used properly in conjunction with MASTER PRODUCTION SCHEDULE PLANNING (see Chapter 4), will enable due dates for all shop orders to be currently valid at all times.

Orders for independent demand items (normally items shipped to customers) are placed on the basis of a forecast of demand. If actual demand exceeds the forecast, there may be a danger of a stockout, and the order due date should be revised. If demand is less than expected, the order due date should be revised also. INVENTORY MANAGEMENT reviews the position of all released orders for independent demand items and reevaluates the original due date. The system alters the due date of the replenishment order and lets the priority based on due date take effect.

When there is contention between two or more orders with the same due date, “tie-breaking” priority considerations are based on factors such as:

- The amount of expected delay (days behind schedule)
- Whether the order has been released early to solve an underload (amount of slack)
- Production parts vs service parts order
- Whether a reduced interoperation time is necessary to meet the due date
- Number of different higher-level order requirements covered (how many planned assembly orders require this part). Figure 40 illustrates this consideration. If this order is delayed, many end item orders may also be delayed.

The basic purpose of ranking orders by priority is to resolve contentions for productive capacity in attempting to meet the due dates of orders. A formal scheme of order priority codes used for “tie-breaking” situations can be set up as part of MANUFACTURING ACTIVITY PLANNING. A method of doing this is through the use of a priority table (Figure 41) which is used to weight priority factors in the calculation of an order’s priority. In the example shown, each priority factor and its status are “looked up” in the table to determine the priority value of each factor and its particular status. These values are then totaled to obtain the order’s priority. ORDER RELEASE PLANNING schedules (loads) orders in their priority sequence for release to the shop.

Initial order priority rules should be simple, and “external” priorities should be assigned judiciously. Procedures for order priority assignment should be under tight management control.

tie-breaking considerations

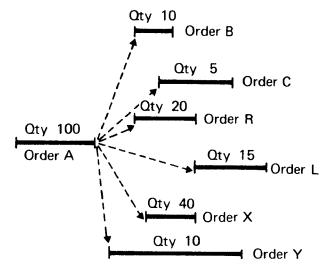


Figure 40. The output from one shop order may be used in many end product orders. The more end products affected, the higher the priority

using order priorities

Priority Factor	Value (Weight) contributed to order priority																						
	-5	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
External Priority			0	1	2	3	4	5		6			7				8						9
Expected Delay (Days)			0	0	0	0	0	2	3	4	5			10			15			25			50+
Reduction of Interop. Time			0	25	50	75	100																
Slack (Days)	999	10	0																				

Figure 41. Actual order priority is obtained from a table that weights each priority element. The table can be altered to reflect management’s overall objectives

Basis of operation priority

OPERATION SEQUENCING determines the sequence for jobs waiting in queue at a work center. This sequence is governed by the relative priority of the operations.

The priority of an operation is based on a number of other factors in addition to order priority. For example, the priority of a job that is subsequently going to an overloaded work center may be reduced.

OPERATION SEQUENCING also considers the following:

- Is the operation on schedule? Priority for behind-schedule operations is increased.
- Should a job already in process on a machine be removed to make room for a more important one? An operation already on a machine is automatically given a high priority.
- Is the next operation performed on the same machine? Jobs with successive operations on the same machine are given priorities to ensure that another job will not intervene.

- Is the next work center “critical”, so that idle time must be avoided at all costs? A low queue in the next work center will cause the priority to increase.
- Is the order due date likely to be missed? This is defined as the number of days the order is expected to be late, as calculated in CAPACITY REQUIREMENTS PLANNING. The bigger the expected delay, the higher the priority.
- Has the order been released early to solve an underload problem? The difference between the early start date and the scheduled start date represents extra “slack” in the schedule for this order. The more slack, the lower the priority.
- Has interoperation time been reduced when the order was processed by CAPACITY REQUIREMENTS PLANNING? The schedule for such an order has less than normal slack. The less slack, the higher the priority.

Expected delay and slack indicate how close the order’s current status is to the original schedule, based on order due date. An order with extra slack is ahead of schedule, a delayed order behind schedule. An order with neither extra slack nor delay either is on schedule, or can be restored to schedule by reduction of the interoperation time. The priority weighting given to these factors can therefore be expressed as one continuous curve (Figure 42).

expected
delay and
slack

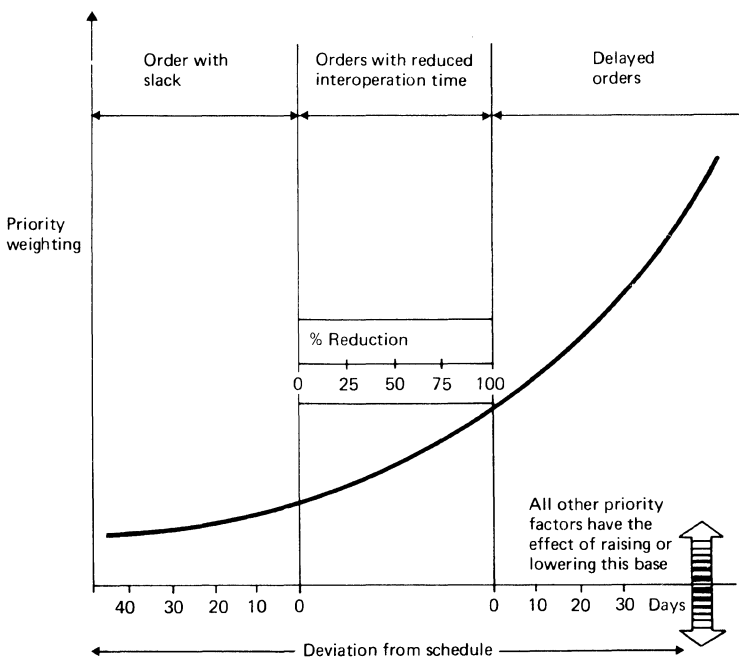


Figure 42. The priority assigned by the system varies with the amount of deviation from schedule

dynamic
ratio

This priority scheme is equivalent to the dynamic ratio sequencing technique, sometimes called critical ratio, which also measures the deviation from schedule. One formula for a dynamic ratio is:

$$\text{dynamic ratio} = \frac{\text{time remaining}}{\text{work remaining}}$$

Time remaining is the interval between the current date and the order due date. Work remaining is defined as the operation time plus interoperation time, that is, the normal lead time allowed from the current operation to the completion of the order. When both factors are equal, the job is obviously on schedule and the dynamic ratio has a value of 1. If these factors are unequal, the job is either ahead of (value of ratio in excess of 1) or behind (value of ratio less than 1) schedule.

For example, if time remaining to order due date is 18 days, and the normal lead time allowance from the current operation to the completion of the order is 20 days, the dynamic ratio value is

$$\frac{18}{20} = .9$$

The order is behind schedule and the current operation will be given priority over all other jobs waiting in queue whose dynamic ratios have values higher than .9.

As time remaining is continuously decreasing, a job not being worked on acquires a progressively lower dynamic ratio, and thus higher priority relative to other jobs. Obviously, ratios for all open orders must be frequently recalculated (once per shift or once a day) to remain valid.

A number of variations in dynamic ratio formulas are in use. One that ranks jobs in queue on the basis of slack per remaining operations is as follows:

$$\frac{(\text{days remaining} \times \text{shift hours}) - \text{std. hours}}{\text{number of operations remaining}} = \text{dynamic ratio}$$

Thus with 18 days remaining to due date, in a 2-shift shop, an order with 12 operations remaining that represent 108 standard hours of setup and run time would show

$$\frac{(18 \times 16) - 108}{12} = 15$$

or 15 hours of slack per remaining operation. The order would be given priority over others that show more than 15 hours of slack per remaining operation. The advantage of this type of dynamic ratio formula lies in taking into account the number of remaining operations, and therefore the number of moves. For each move, a wait in queue can be assumed. This approach is a refinement over a priority based on total slack in the schedule of the order.

The shortcoming of these types of priority techniques is the “blindness” of the dynamic ratio derived. Based on the factors that enter into the calculation of the ratio, the formula may assign a top priority to a job whose next operation must be performed on a machine that is currently down or is tied up by a long-running job. Dynamic ratios lack the “lookahead” feature utilized in OPERATION SEQUENCING.

OPERATION SEQUENCING simulates how jobs will move on the shop floor (see “Operation Sequencing”). The priority of each operation is calculated at the time of its simulated arrival at the work center. Only at this time are the operation priority criteria considered.

calculation
of operation
priority

Order Release Planning

Capacity decisions made as a result of CAPACITY REQUIREMENTS PLANNING ensure that, on the average, work center output will be sufficient to meet the expected workloads. However, controlling the level of *output* may not be enough.

In Figure 43 jobs A and B have their first two operations on the same work centers. Job A has the higher priority and precedes job B through these work centers. Job A then has to wait at work center 113 because of higher-priority work in the queue.

At the same time, work center 114 is underloaded because work is not yet available. If this had been known beforehand, job B could have been released earlier and done first in work centers 111 and 112, thus reducing idle time in work center 113, without causing a further delay to job A.

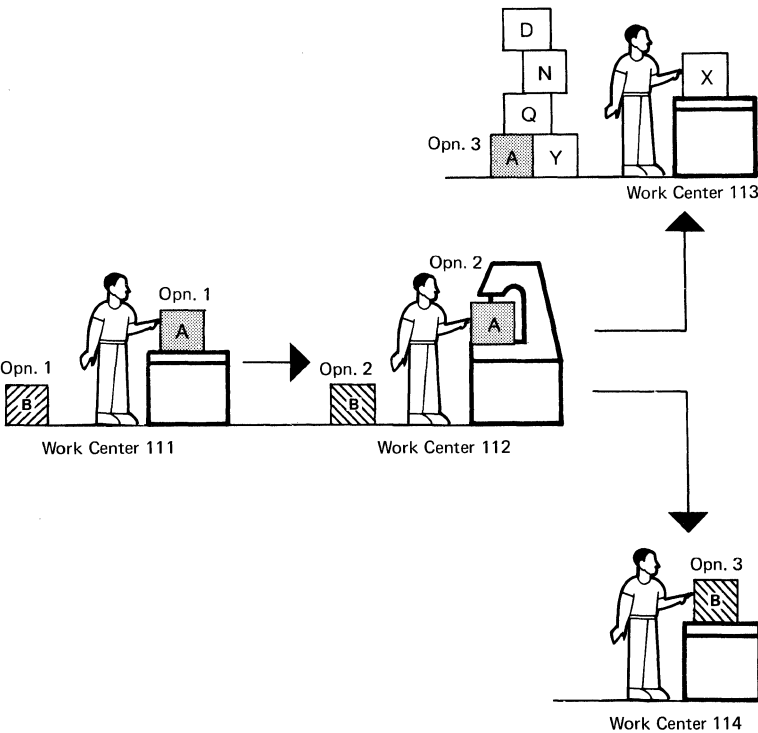


Figure 43. The unplanned release of orders causes delays and idle machine time

This “lookahead” is a major function of ORDER RELEASE PLANNING and its effect is to regulate *input* to the plant.

It should be noted that the norm for releasing an order is the *planned order release date* established by MATERIAL REQUIREMENTS PLANNING, which also schedules raw material to be delivered on (or slightly ahead of) this date. Therefore the availability of raw material normally represents the constraint for early order release. However, an economic lot sizing decision may provide material availability to allow for early order release.

The number of order release dates modified in ORDER RELEASE PLANNING depends primarily on the variation in the load profiles. Where loads are fairly constant, few changes are required (Figure 44C). If the level of planned capacity can be frequently varied, the number of changed order release dates can be reduced (Figure 44B). With high variability and a constant capacity, many orders may have to be moved (Figure 44A).

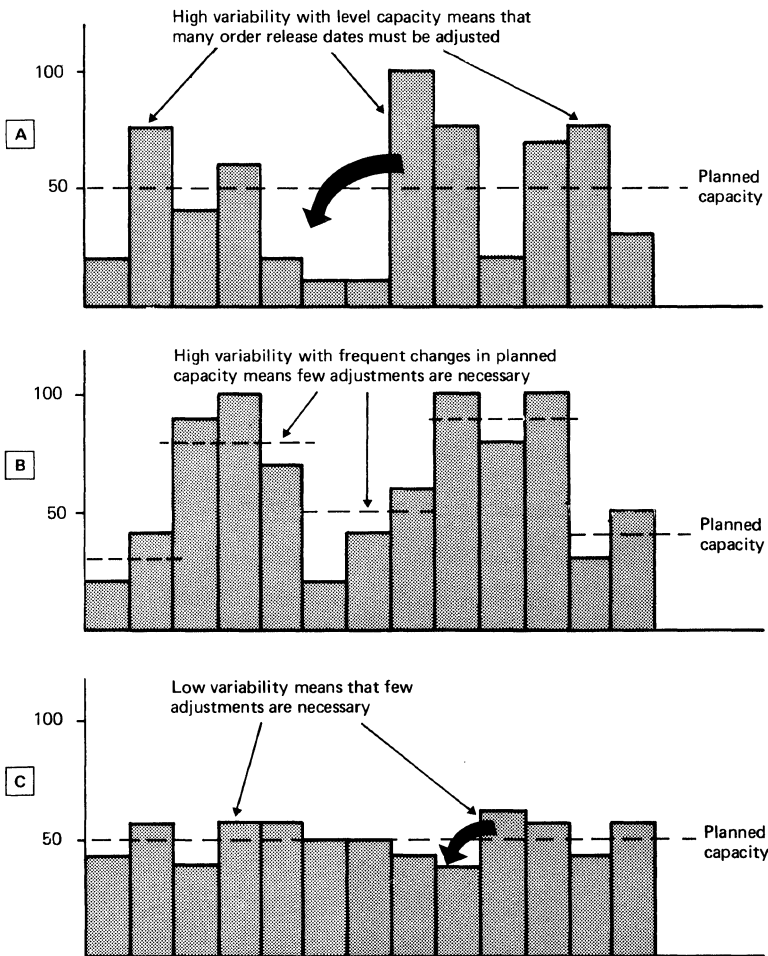


Figure 44. The higher the variation in the load profile, the more planned release dates must be altered to achieve a level load

Basic steps

In determining when to release an order, the system performs the following basic steps:

- Determine order priority (see “Priorities”). In most cases the planned order release date established by MATERIAL REQUIREMENTS PLANNING reflects this priority.
- Starting with the highest-priority order, load each work center on the basis of the operation start dates assigned in CAPACITY REQUIREMENTS PLANNING. Continue loading until any maximum capacity specified in CAPACITY REQUIREMENTS PLANNING is reached.
- When an overload is detected, the operation is moved to the closest period that is not overloaded (Figure 45). The number of periods it can be moved from its planned date depends on the slack between the earliest and latest date the operation can be started. If an operation date is moved, the other operations on the order may also be moved, in order to reduce the overall lead time.
- If the operation cannot be scheduled by the latest start date, check for the existence of an alternate work center or routing. If an alternate is designated, and available, it is loaded. An alternate could be a subcontractor or another plant.
- If alternatives are not available, reschedule the release date and, if necessary, the order due date, until the order can be loaded. Notify management of any delayed orders. If end item orders will be delayed, the master production schedule should be changed accordingly.
- Check which orders can be released early in order to fill up any underloads.
- Estimate completion dates on all orders based on when operations are scheduled.

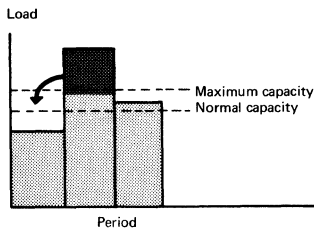


Figure 45. The system attempts to locate capacity for an order

Overtime planning

The amount of overtime that can be planned is limited by “maximum capacity” (see “Work Capacity”). The system assumes that capacity can always be made available up to this limit, and automatically loads up to it.

When the system has finished scheduling all planned and released orders, the resultant leveled load profiles will indicate the actual amount of planned capacity utilized (Figure 46). This plan is used as a basis to authorize overtime by work center.

Any decision to override this maximum, for example, to complete some urgent work, should be made by management and not by the system. This can be specified here or on a daily basis in **PLANT MONITORING AND CONTROL**. Unresolved underloads will also be indicated.

Management may want to implement short-term adjustments to utilize excess labor capacity. If so, these can be indicated as in **CAPACITY REQUIREMENTS PLANNING**.

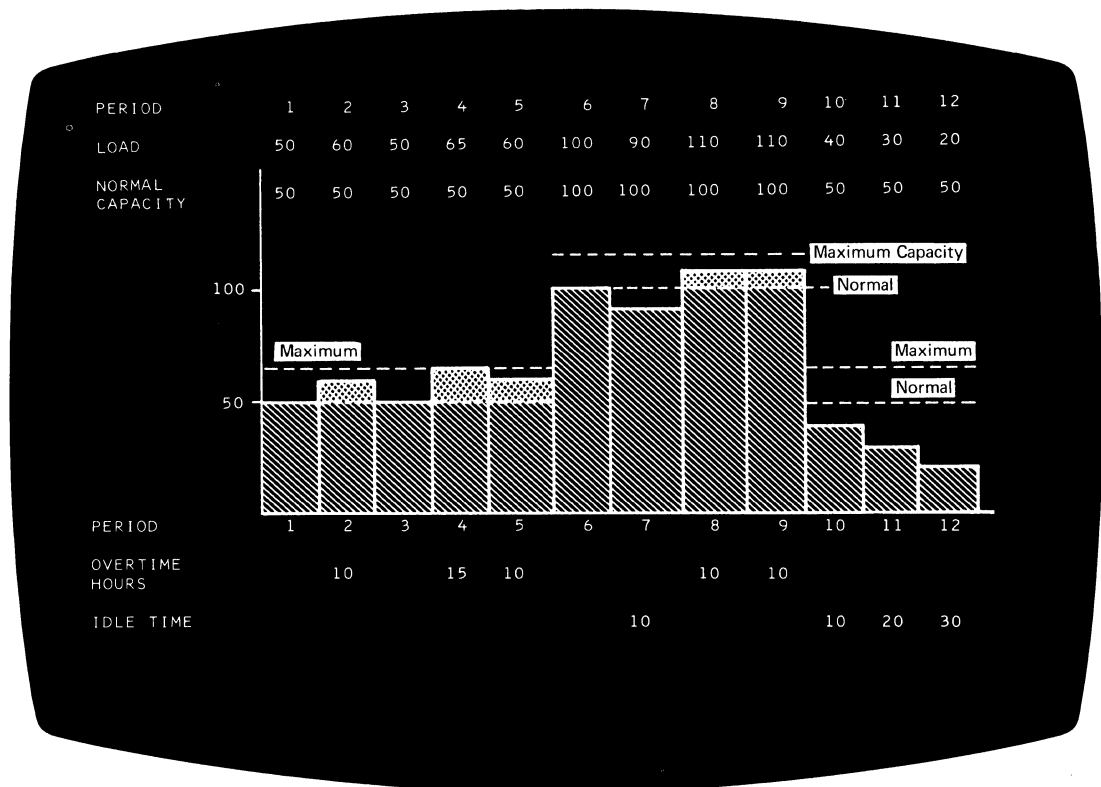


Figure 46. The results of **ORDER RELEASE PLANNING** can be displayed as a load profile. This serves as a basis for overtime authorization

Early release of orders

ORDER RELEASE PLANNING resolves underloads by releasing some orders earlier than originally planned. However, early release of an order, in an attempt to level the load at a certain work center, does not necessarily result in an early completion; this depends on the order priority and on the situation at other work centers required by the order.

Generally, an order released early will have low priority because of the “slack” in its schedule. Because of its low priority it spends more than the average time in queue at some work centers. Gradually the slack is absorbed, the priority increases, and the order is completed close to its original schedule. Idle time at some work centers is thus prevented, but at the cost of work-in-process inventory.

Some companies try to keep their “gateway” or initial work centers busy. This can cause the early release of orders. Because later work centers are not considered, these early-release, low-priority orders may spend many days at other centers. Therefore, lead time is extended with a corresponding increase in work-in-process.

In choosing orders for early release, ORDER RELEASE PLANNING checks capacity in *all* work centers involved and so prevents excessive “stretching” of the lead time.

Postponement of due dates

Postponement of order due dates is considered as a last resort and should rarely be required if CAPACITY REQUIREMENTS PLANNING has been properly performed in the early stages.

If an order is released without available capacity, it waits in queue, increasing shop congestion and work-in-process inventory until its dynamic order priority becomes high enough to get it moving. Early release does not result in its getting done any earlier, because the system holds the order until capacity is available. The effect of postponing an order release because of a capacity shortage is shown in Figure 47.

Using Order Release Planning

ORDER RELEASE PLANNING is the “fine tuner” that maintains the balance between loads and capacities in the short term. It determines the actual capacity requirements between the normal and maximum available capacities, and it adjusts order release dates, using logic specified by management.

It usually considers only the short-term horizon (several weeks in the future). In the coming week, plant management is usually committed to providing the capacity specified, and orders will be released according to the dates established (see *Chapter 7, Order Release*).

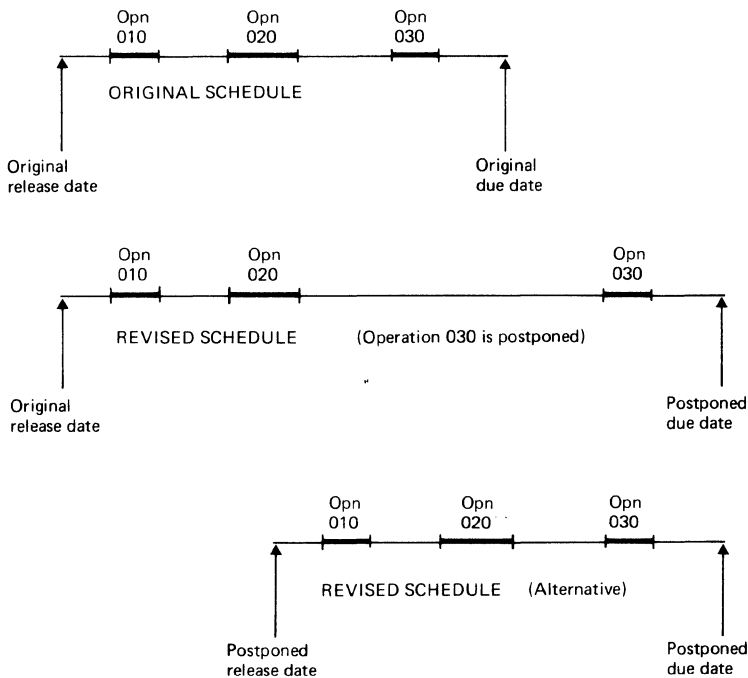


Figure 47. This indicates the effect of postponing the release of an order because of capacity overload. The order is still finished on the same day, but is on the shop floor for a shorter length of time

When requested, the system can provide complete information on the following:

- Orders whose due dates have been postponed
- Orders whose release dates have been modified (either advanced or postponed)
- An order status report for any order (as in CAPACITY REQUIREMENTS PLANNING)

management
information

Simulating changes to capacities and orders

Shortage of capacity revealed during MANUFACTURING ACTIVITY PLANNING can be resolved by a trial adjustment to the available capacity at a work center. When MANUFACTURING ACTIVITY PLANNING is rerun, the output shows the direct effect of the capacity change on future orders.

By extending the technique of changing either the input or the constant values, such as capacities and operation times, it is possible to use MANUFACTURING ACTIVITY PLANNING as a simulator. The information obtained by comparing a mix of orders having fixed due dates against a fixed capacity includes:

- Work center load profiles that show machine overloads and unusable capacity, and labor overtime and idle time
- Order release dates that indicate how long the order will be in process
- Orders that cannot be completed on time, along with the number of days late

MANUFACTURING ACTIVITY PLANNING calculates the effect on loads, and on order-release and due dates, of changes to the order mix and plant capacities. The capacities include, in addition to available machine hours, such resources as transport, labor, plant layout improvements, and individual machine speeds.

When input to MANUFACTURING ACTIVITY PLANNING is altered to reflect a proposed change, it is possible to calculate the effect of:

- Changing the capacity of a machine or work center, for example, by the addition of an extra shift.
- Changing the order mix — for example, a dummy order file can be used to represent a major change to the master production schedule or to calculate the effect of a single additional order.
- Changing the shop floor layout or introducing improved materials handling techniques, thus causing changes to the wait and move times between work centers.
- Introducing a new machine that causes a reduction in run time on operations performed in the work center.

Simulating such changes can improve the accuracy of selection between alternatives. For example, a plant layout change or the acquisition of a new machine will usually have effects beyond those assumed in the conventional justification process. Simulation may reveal that the change would lead to a reduction in work-in-process and to greater savings than originally expected. The effect on work-in-process would be difficult to observe and measure without a simulator.

OPERATION SEQUENCING is a simulation of what is likely to happen on the shop floor, given the current production plan and existing manpower and machine availability. It attempts to schedule the jobs in the sequence the foreman would use if he had the time and necessary information to make a decision that would consider the plant as a whole.

The sequence decided on by the foreman depends not only on priority but on considerations such as machine utilization, grouping together jobs with common setup, skill of the operator, tolerance of the machine, material and tool availability, etc. He knows approximately when each of the jobs will be completed and authorizes overtime as necessary to get through the backlog and clear urgent jobs.

What he does not know is which jobs will arrive in his department and *when* they will arrive.

If he could know in advance about high-priority jobs that will arrive in his department, he would not tie up machines with long-running operations that later have to be interrupted to do the urgent work.

Operation Sequencing versus priority listings

How does the foreman know which jobs to do first? Usually from a priority list provided by Production Control or printed by the computer, on a daily or weekly basis. This listing normally indicates late work, shortages, and other high-priority jobs.

However, a listing of scheduled jobs simply by priority does not indicate *when* the jobs will arrive. Only a work sequence list supplied by OPERATION SEQUENCING gives shop management and Production Control the information to foresee events such as outlined above.

Figure 48 illustrates the major difference between a priority list and an operations work sequence list. Operation 1 on order A is done in the turning department, where there is a queue of much higher-priority work. Operation 2 is done in the milling department, where order A has a high priority in relation to all the other work there.

Priority list for
work center 1

TURNING DEPT.		
JOB	OP.	PRIORITY
X	1	19
Z	6	18
M	7	14
N	10	13
O	9	13
Q	4	12
E	3	12
A	1	10
T	4	7

Priority list for
work center 2

MILLING DEPT.		
JOB	OP.	PRIORITY
A	2	10
F	3	9
G	1	9
H	7	7
J	2	6
L	1	6
K	1	5
Y	2	5
D	4	4

Work sequence
list for
work center 1

TURNING DEPT.		
JOB	OP.	PRIORITY
X	1	19
Z	6	18
O	9	13
M	7	14
T	4	7
Q	4	12
A	1	10
E	3	12
N	10	13

Work sequence
list for
work center 2

MILLING DEPT.		
JOB	OP.	PRIORITY
D	4	4
H	7	7
F	3	9
G	1	9
L	1	6
J	2	6
Y	2	5
A	2	10
K	1	5

Figure 48. Operation sequencing provides a more realistic work list for
shop management

Using a priority list, the milling foreman knows A to be the highest-priority job to be done in his department and is expecting it. Not knowing when it will arrive, he may either reserve capacity for it or do other work and risk having it interrupted.

In preparing the work sequence list, on the other hand, the system determines when previous operations are expected to be completed and approximate arrival sequence in the next department. That is, by calculating the operation priority on the basis of planned availability, it gives a sequence incorporating priority *and* availability. Knowing approximately when jobs will arrive, the foreman can plan better. The approximate time of day that the job will arrive can also be shown if required.

work
sequence
list

Figure 49 shows an example of a work sequence list for a work center. It may be printed or displayed for dispatching the work to the operator via a terminal, as described in *Chapter 8, Plant Monitoring and Control*.

WORK CENTER	75205	RADIAL DRILL		NUMBER OF MACHINES 1		AVERAGE DAILY CAPACITY				16.0 HRS	
DAY NO.	AVAIL HRS	LOADED HRS	PERCENT	IDLE HRS	TIME PERCENT	0	20	40	60	80	PERCENT 100
881	14.0	14.0	100	0.0	0	*****					
882	16.0	12.3	77	3.7	23	*****					
883	16.0	16.0	100	0.0	0	*****					
TOTAL	46.0	42.3	92	3.7	8						

SHOP ORDER NO.	ITEM NO	DESCRIPTION	OP. NO.	TEXT OF OPERATION	AVAIL -ABLE	QTY	OPN. HRS	SET-UP HRS	LAST WC-NO END	NEXT WC-NO START	PLAN WC
05510	003204	SCRAPER	020	CHAMFER	::	1000	3.5	0.0	61001 880	75310 883	
05530	220121	GRIP UNMOUNTED	080	DRILL AND CHAMFER	::	500	10.1	0.4	75204 880	75207 886	
05509	003204	SCRAPER	020	CHAMFER		1000	3.5	0.0	61001 881	75310 885	75637
05526	003210	ADDITIONAL SUPPORT	060	DRILL		400	7.8	0.2	75303 882	75301 889	
05501	220121	GRIP UNMOUNTED	080	DRILL AND CHAMFER	::	100	2.0	0.4	75204 881	75207 886	
05515	003216	ADDITIONAL SUPPORT	060	DRILL		400	7.8	0.2	75303 881	75301 884	
05516	003217	ADDITIONAL SUPPORT	090	DRILL		800	16.0	0.2	75303 882	75201 888	
05517	003210	ADDITIONAL SUPPORT	090	DRILL		800	16.0	0.2	75303 884	75201 890	
JOB QUEUE 05502	220121	GRIP UNMOUNTED	080	BORE AND CHAMFER		500	10.1	0.1	75204 887	75207	

Figure 49. Work sequence list

To be successful the list must take account of the current status of all production facilities and should, therefore, be run as frequently as practical. In industries having a large volume of short operation times this may be at the end of each shift; in industries having longer operation times this may be daily or every few days. Figure 50 illustrates the advantage of producing the operations sequence dispatch list as frequently as possible.

OPERATION SEQUENCING incorporates many of the features of current shop practice. For instance, if it is practice to overlap certain operations or group together jobs with similar setups, the system can simulate these features.

The foreman, in conjunction with Production Control, has the final say in assigning jobs to the operators and machines. The operation sequencer gives him the best information on which to base decisions.

Assigning work to individual machines

When operations at a work center are being sequenced, do machines have to be assigned individually or can the work center be treated as a whole?

Many work centers can be treated as a whole without considering individual machines or capacities. Such centers are characterized by:

- A large number of like machines and labor skills, where it is immaterial which machines or men do the job.
- Many short operation jobs, where it does not matter too much which job is done first as long as all operations are completed on the scheduled date.
- Process-type operations, such as spraying or washing, where capacity is not easily defined and any job can reasonably be done within a specified time, say 24 hours.

In these work centers, the exact sequence does not matter and will often be decided by the foreman. A daily work list based on operation start date and order priority, as calculated in ORDER RELEASE PLANNING is usually adequate.

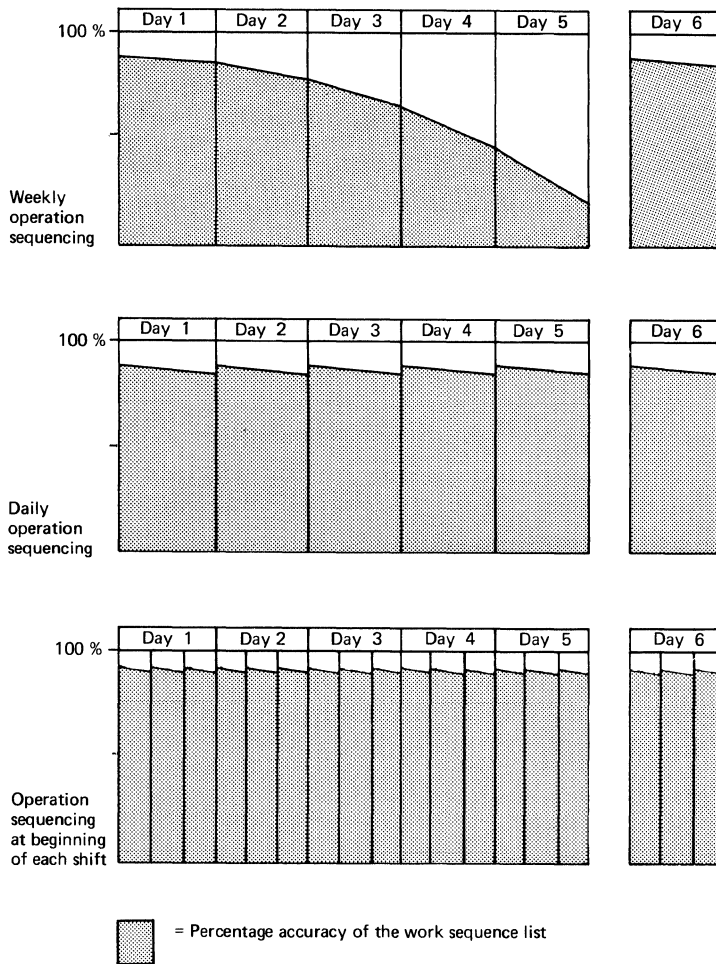


Figure 50. Frequent operation sequencing provides greater accuracy in the work sequence list

However, in other work centers, jobs are allocated to individual machines during sequencing to try to get as close as possible to what will actually happen on the shop floor. The characteristics of such work centers are:

- Machines or men with widely varying capacities (for example, some machines run two or three shifts)
- Machines or men with varying capabilities or skills (for example, the routing specifies tolerances that can be achieved only on one machine in the group, or on certain machines with particular characteristics, such as a threading attachment)
- Long operation times, or a wide range of varying operation times
- A critical work center or one where minimum idle time is essential (for example, numerically controlled machines would normally be individually sequenced in order to plan for maximum utilization)

However, the allocation to individual machines should be considered only as a guide to the foreman. He may change either the sequence or the allocated machine on the basis of other factors that may not be coded on the Routing, such as labor skills, tolerances on the machine, etc. How the foreman assigns the work from the work sequence list is described in *Chapter 8, Plant Monitoring and Control*.

Function of Operation Sequencing

Input to OPERATION SEQUENCING comes from ORDER RELEASE PLANNING, which establishes a realistic start date for each operation, based on order priority and capacity limitations.

Because ORDER RELEASE PLANNING considers a large volume of orders over a period of weeks, it is normally run only once every few days. OPERATION SEQUENCING considers only the operations to be performed the next day or so and is therefore run much more frequently – usually daily or once per shift. If it is run daily, the planning horizon (Figure 51) is normally two or three days ahead. This gives the foreman an idea of the workload over the next few days and allows the operation sequencer to do a better job of balancing the loads.

feedback
from the
shop floor

With such frequent processing, account must be taken of what has happened on the shop floor over the past few hours. This feedback is described in *Chapter 8, Plant Monitoring and Control*.

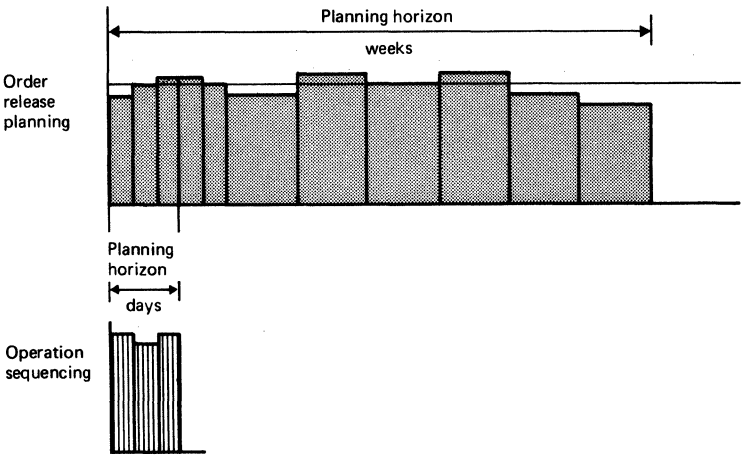


Figure 51. OPERATION SEQUENCING is run daily for each shift with a horizon of only a few days

Notification of completed operations, partial completions, interruptions, machine breakdown, overtime authorization, employee absenteeism, etc., is fed back via shop floor terminals to update the shop order records before OPERATION SEQUENCING. The new work sequence list therefore reflects the status of work on the shop floor immediately before the start of the shift.

Sequencing the Operations

The method of sequencing is based on operation priority (described earlier in “Basis of Operation Priority”) together with some special considerations such as grouping jobs with similar setup, tool availability, etc. These special considerations are discussed later in this section.

Sequencing of operations is performed in three steps:

- Establishing the hours available in a work center
- Sequencing work from the queue
- End-of-shift routines

Establishing available hours

The basis for establishing the hours available on each work center or machine is to specify the particular hours of the day it will be available. Staggered working hours can be shown by varying the start/stop times for a work center or machine.

When sequencing operations, the system uses an internal 24-hour clock to simulate the actual scheduling of operations in the plant. Specifying actual start/stop times for each machine enables better sequencing decisions to be made. For instance, the sequencer would not plan to do a heat-treat operation at the end of the shift if the subsequent operation had to be performed within two hours and the next work center were working on a one-shift basis.

During processing, the clocks simulate the time of day and indicate when each machine will be available for the next job. The system keeps track of idle time expected between successive jobs on a machine because of unavailability of another job (Figure 52).

keeping
track of
idle time

Total idle time expected for the day, or shift, can be shown on the work sequence list illustrated in Figure 49.

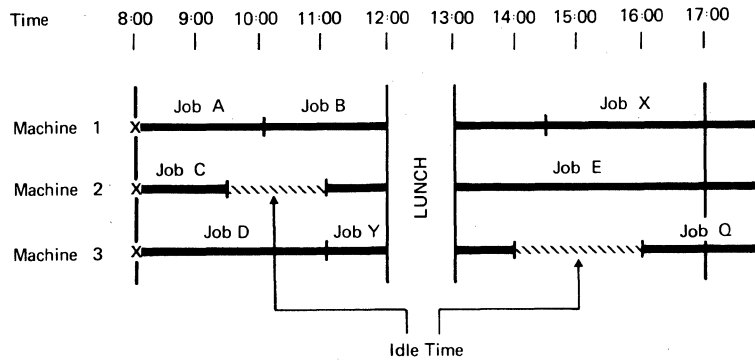


Figure 52. The system keeps track of idle time expected at each work center because of the unavailability of work

Sequencing work from the queue

The principle of sequencing is that all work centers are cyclically processed in turn. During one cycle all jobs queuing at a work center are considered for assignment. Work is assigned for a specified period of time ahead (20 minutes, 1 hour, 2 hours, 4 hours, etc.). When all work centers have been processed, the clock is moved forward and processing repeated for the next cycle.

During each cycle, work expected to be completed at a work center becomes available for processing at the next work center after interoperation time, shift length, etc., are considered (Figure 53).

Length of time increment. The length of the cycle period can vary from minutes to days. The shorter the period, the more accurate the results. A longer increment, however, reduces computer processing time.

Work center sequence. The work centers themselves can be loaded in any sequence. In most industries there are certain “gateway” or first-operation departments (material cutoff, foundries, turret lathes, etc.) that ought to be sequenced first because they release work to later work centers.

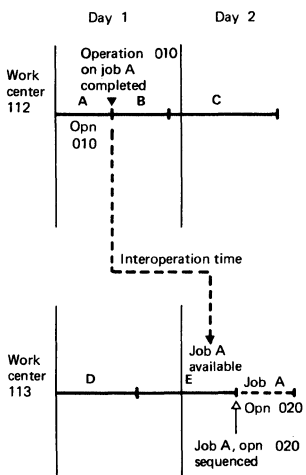


Figure 53. Work is sequenced at the next work center at the end of the allowed interoperation time

jobs
available
for
sequencing

At the start of processing, the first work center queue is checked for all operations available for sequencing. An operation is available for sequencing when all previous operations have been completed and components are available.

The operation priority is now calculated for all jobs in the queue and the job with the highest priority is loaded on the first machine (see “Basis of Operation Priority”). The next highest priority job is loaded on the second machine, and so on, until every available machine in the work center has been assigned one job.

The clock for each machine is incremented by the operation duration (setup time + run time + teardown time).

The next job is now loaded onto the first available machine in the work center (machine 3 in Figure 54), and so on, until the capacity within the cycle period is used up or until all available jobs meeting the operation priority criteria are sequenced.

After an operation has been sequenced onto a machine, the completed job is made available for sequencing at the next work center. The availability date and time is determined by using the interoperation time calculated earlier. The queue time is excluded because the actual queue is being simulated by this process.

The next work center is now loaded in a similar manner from the available jobs in its queue.

When all work centers have been sequenced, the clock is incremented and processing starts again at the first work center. Sequencing then goes on for each machine from the time it left off.

Next time around, the queue now contains operations previously available but not sequenced, as well as new operations available as a result of just being completed on other work centers.

The sequencing is continued to cover a period of one or more days, as required.

End-of-shift routines

When work has been sequenced up to the end of a shift, the system sets the clocks to coincide with the start of the next shift. It also checks for any scheduled jobs that will be delayed beyond their start date; these jobs have not yet been sequenced and their start date will now be later than that planned in ORDER RELEASE PLANNING.

The system checks back through the shift to see what work could have been sequenced onto alternate work centers.

basic steps of sequencing

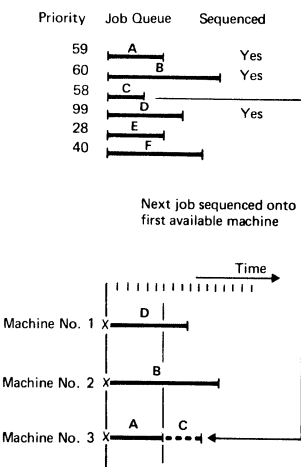


Figure 54. Sequencing is performed by loading the next highest priority job on the next available machine

selecting
alternate
work centers
at end of
shift

The operations that are running late are scheduled, if possible, for alternate work centers if capacity is available. Each work center will be looked at in turn, in a predetermined sequence, for work to offload.

Work centers having idle time above a specified figure can also be checked to see whether work can be offloaded from other work centers. Alternate operations or routings are checked for during the sequencing process.

overtime

The level of overtime necessary to meet the schedule has been determined by management as a result of CAPACITY REQUIREMENTS PLANNING and ORDER RELEASE PLANNING. Operations are sequenced up to the specified level of overtime above the normal working hours.

Special Considerations

During the sequencing process, the operation priority and latest start date were taken as the major criteria for the work sequence. But other factors were also considered — for example:

- *Operation grouping* — pulling together jobs with similar setup to fill a furnace, etc.
- *Time-critical operations* — where a subsequent operation has to be performed within a certain time of the previous operation (for example, because of cooling after heat treatment)
- *Related facilities* — where two or more facilities must be available together to perform the operation (man and machine, tool and machine, etc.)
- *Overlapped and split operations* — consideration of the overlapping and splitting decisions made earlier
- *Alternate operations and routings* — consideration of the use of alternate facilities to prevent operations from being delayed
- *Split lot sizes* — sequencing the send-ahead and remaining parts of a split lot
- *Operations done out of sequence* — since the sequence in which operations are performed is sometimes immaterial on jobs with a large number of operations

Grouping operations

In each industry there is a need to group similar operations together. The main reasons are:

- **Economic** – where operations with similar or equal characteristics can be combined to reduce the load, as in the case of operations with similar setups
- **Technical** – where it is necessary to process, say, a minimum batch size at one operation. An example would be the capacity of an induction furnace or oven.

Each operation to be considered for grouping can be given a grouping code that governs the creation of a batch (Figure 55). Because of the variation in requirements throughout industry, such a code would be determined by the individual company.

A sequence number included in the code indicates in which sequence the different operations in the batch are to be run. For example, they could be used to indicate temperature gradients in heat treatment, or color change in plastic extrusion or dyeing.

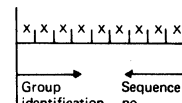
It is not sufficient to group just on the basis of a code. For instance, it would normally be undesirable to group together operations with start dates many weeks apart. Certain practices can be followed to limit or extend the degree of grouping:

- Limiting grouping to jobs within certain priority ranges.
- Imposing restriction based on time; for example, operations are not to be performed more than say five days early for grouping purposes (Figure 56).
- Having minimum and maximum lot sizes apply at a work center; for example, because of vat size or container size, jobs may have to accumulate to the minimum lot size.

Time-dependent operations

Certain operations are time-dependent – that is, they must be followed by another operation within so many hours. Examples of such operations are:

- Extruding after a heating operation
- Bonding after preparing the surfaces
- Vulcanizing “green” rubber that has a limited life
- Forming after annealing

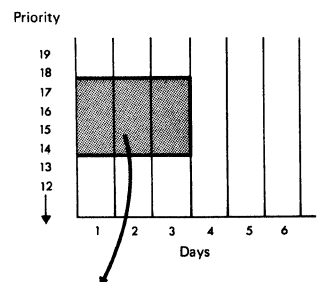


Example

Shop order A grouping code	11217 4
Shop order B " "	11237 9
Shop order C " "	11724 31

Work center	No. of digits checked for grouping code	Orders which can be batched
112	First one only	A, B, C
114	First two only	A, B

Figure 55. Grouping code allows similar jobs to be batched to make maximum use of a facility



Example

Priority 17 orders can only be batched within this range of priority and date

Figure 56. Limitations can be placed on which shop orders can be grouped together

The first operation is sequenced at its work center queue in normal priority sequence. The succeeding operation must be sequenced at the next work center, not in its normal priority sequence, but within a strict time limit of the first operation. It is then sequenced onto the first individual machine available. This may be repeated for subsequent operations if necessary.

charging

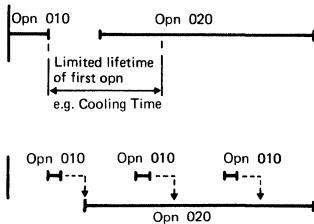


Figure 57. Operations may have to be split because of a limited "life"

In many process-type operations, the maximum lifetime of the first operation may be less than the length of the second (Figure 57). In process industries this is often called "charging". An example is the annealing of a lot size in small sections because of the hardening time prior to the next forming operation.

If this problem exists, the first operation would be split into several lot sizes which, when scheduled, will not cause this limited lifetime to be exceeded.

Related facilities (tools, men, machines)

A problem often arising on the shop floor is that two or more facilities have to be available at the same time to work on the operation. This may be machines and men, or tools and machines, etc.

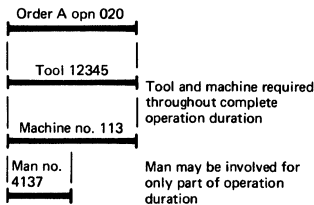


Figure 58. OPERATION SEQUENCING checks for availability of a number of related facilities

This is illustrated in Figure 58, where a combination of several facilities is required. The system determines the highest-priority operation and schedules it first. A second shop order requiring the same tool cannot be scheduled (loaded) until the operation on the first order is completed. The second order may thus incur a delay and other work would be scheduled ahead of it.

tool
requisitioning

Contention for these facilities on intermediate operations can be checked only at the time of the sequencing of operations, not at the time of order release. For operations subsequent to the first one, the time that a tool is needed is determined by the operation sequencer. It may be automatically requisitioned at that time or on request, as described in *Chapter 8, Plant Monitoring and Control*.

Overlapped and split operations

Overlapping and splitting of operations planned in CAPACITY REQUIREMENTS PLANNING is reconsidered here in light of the machine and manpower availability. For instance, in split operations, only one of two machines may prove to be available because the other planned machine is tied up with a high-priority job (Figure 59).

Wherever a further delay occurs in OPERATION SEQUENCING, the delayed operation can be checked to see whether it can be overlapped with the succeeding operation (Figure 60). The same rules apply as described earlier in "Capacity Requirements Planning".

If the succeeding operation is still late after overlapping, the process is repeated on all subsequent operations until either the due date is met or no further overlapping is possible.

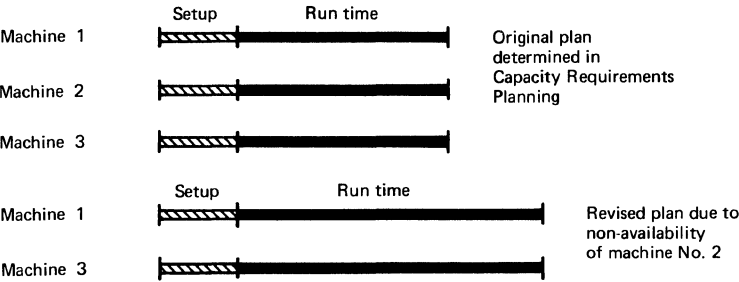


Figure 59. It may not be possible to run an operation in parallel on a number of machines as planned

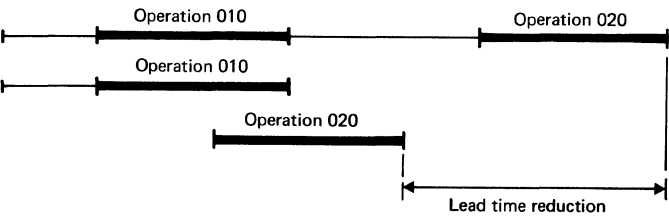


Figure 60. Overlapping of operations to reduce a delay

Alternate operations/alternate routings

Use of alternate routings or alternate operations is determined during the sequencing process itself and not at the end of shift as in the case of alternate work centers. It is assumed that, if an alternate operation or routing has been specified, it would be the choice of the planner, should the normal work center not be available.

Alternates are used if the original operation is late, or if underloaded work centers need to be supplied with work, or if the sum of alternate operation and interoperation time is less than that of the original operation, for example, where an operation normally done at another plant is made in-plant because of shortage of time.

A further reason for choosing alternate routings is the need to use different materials, such as larger-diameter bar stock. These decisions, however, are not based on scheduling problems and therefore the decision to use an alternate must be made outside OPERATION SEQUENCING (see “Implementing Changes to Shop Orders” in *Chapter 8, Plant Monitoring and Control*).

The system can accept three types of changes:

- Replace the original operation with an alternate operation – for example, do it on turret lathes instead of engine lathes.
- Replace the original operation with more than one alternate operation – for example, replace one operation on an automatic lathe by three operations on turret lathes, drills, and mills.
- Replace the current operation and all subsequent operations with an alternate routing.

Order splitting

If it was decided in PLANT MONITORING AND CONTROL to split an order out on the shop into two separate lots, then OPERATION SEQUENCING reschedules them as separate orders, the send-ahead quantity being given a higher priority.

Operations performed out of sequence

In some situations the sequence in which the operations are specified by the routing may be altered. In some cases the foreman may do this to level the loads or reduce idle time; in other cases the manufacturing routing may not be correct.

When an operation is completed out of sequence, it is reported from the plant floor and checked (see “Implementing Changes to Shop Orders” in *Chapter 8, Plant Monitoring and Control*). OPERATION SEQUENCING will then schedule (load) all remaining operations in their original sequence unless otherwise specified.

Plant Maintenance

The planning of maintenance work orders has to be closely related to MANUFACTURING ACTIVITY PLANNING, because both systems are planning the use of the same facilities. Maintenance work orders are therefore included during the Operation Sequencing phase of MANUFACTURING ACTIVITY PLANNING in particular. The advantages of doing this are:

- Maintenance work orders are sequenced in during idle time on machines.
- High-priority orders are not delayed because of machine unavailability.
- The time maintenance workers spend waiting for the machine to become available will be reduced.
- Jobs can be routed onto alternate machines or work centers when maintenance is scheduled on the original machine.
- High-priority maintenance work is not held up indefinitely.

MANUFACTURING ACTIVITY PLANNING is the key to successful control of the activities that take place on the shop floor. The system's objectives are:

- Meeting delivery dates
- Controlling work-in-process
- Controlling manufacturing lead times
- Preventing bottlenecks
- Minimizing idle time

This is done in three stages:

- **CAPACITY REQUIREMENTS PLANNING** — establishes the earliest and latest start dates for each operation and defines the capacity required to meet the master production schedule. If the schedule is to be met, management must provide this capacity — by subcontracting, authorizing overtime, hiring new labor, etc. Interactive techniques using graphics terminals can help management decide capacity levels and determine the best orders to subcontract in cases of overload. The capacity level establishes the planned output from the plant. CAPACITY REQUIREMENTS PLANNING works primarily on a net change basis. New and changed orders from INVENTORY MANAGEMENT, as well as existing orders requiring rescheduling, can be processed as the need arises, without necessarily rescheduling all orders.
- **ORDER RELEASE PLANNING** — regulates input to the plant by determining an order release date and estimated start date for each operation to achieve a level load. This is based on the capacities set in CAPACITY REQUIREMENTS PLANNING and on order priorities. ORDER RELEASE PLANNING is primarily a batch system — that is, all orders are rescheduled at frequent intervals, say every two days or weekly, because changes to even a few orders tend to affect all remaining ones.
- **OPERATION SEQUENCING** — sequences, according to an operation priority, all work planned to be available during the next few days. This is done daily or at the end of each shift. It provides the basis for assigning and dispatching work in the plant, as described in *Chapter 8, Plant Monitoring and Control*.

Changes to the master production schedule occur continuously.

MANUFACTURING ACTIVITY PLANNING reflects these changes to the shop floor. It is an iterative process, and each stage depends upon the results of the previous stage — that is:

- Planning to release orders to the shop without sufficient capacity being available increases queues and lead times.
- Sequencing jobs without looking ahead for bottlenecks results in an improper overall workflow.

MANUFACTURING ACTIVITY PLANNING is designed to help management utilize plant facilities to the maximum.

Chapter 7. Order Release

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ORDER RELEASE provides the connection between the planning and implementation phases of the Communications Oriented Production Information and Control System concepts. The primary output of the planning phase consists of planned orders, which are specified by release date and quantity. Up to the time of order release, the planned order usually represents no commitment of resources and therefore can be easily altered. The function of ORDER RELEASE is to change the status of the order from “planned” to “released”. Shortly after release, either a purchase order will be placed or operations started on manufactured components and subassemblies. Therefore, it is usually difficult and expensive to alter an order after it is released.

System objectives

Unless each order is committed for production or purchase on its planned release date, much of the previous planning is wasted effort. ORDER RELEASE ensures that each planned order is released on the planned date.

MATERIAL REQUIREMENTS PLANNING schedules components and materials required for shop orders so that they will be available at the time of order release. However, because suppliers fail to deliver on time or because upsets such as machine downtime occur on the shop floor, material is not always available on the specified date. Before authorizing release, therefore, ORDER RELEASE checks the inventory record to see that the required material is available. Available components are allocated to released orders; this is in lieu of the “physical staging” (or pre-pulling) of components now practiced by many companies. In ORDER RELEASE staging is simulated by the system and floor space is not tied up. In a similar manner the system can check for tool availability.

Once release is authorized, the system generates Action File notices that initiate the picking of the required materials, components, and tools, and the gathering of required drawings and, if applicable, tapes for numerically controlled machines. The system automatically generates other shop order documentation that will accompany the shop order. This includes a printed manufacturing routing and shop order identification card. The card is used to report, via terminals located on the shop floor, all manufacturing activity affecting the shop order.

ORDER RELEASE is so designed that it can quickly issue new documentation and set up control records when required — for example, for rush orders.

System functions

Figure 1 illustrates the following basic functions of ORDER RELEASE :

- The planned order release dates established by the previous planning systems are periodically reviewed. At date of release, the detailed functions performed by the release system depend on whether the particular order is a shop or purchase order.
- For shop orders, the physical availability of materials and tools required for initial operations is checked. Only those orders that have available all materials and tools are released — those on which manufacturing activity can proceed.
- If material and tool availability is adequate, components not previously allocated during MATERIAL REQUIREMENTS PLANNING are now allocated. This helps ensure that components in short supply are issued to high-priority orders.
- Material and tool requisitions are generated for stores.
- Shop order documentation is prepared and Action File notices are generated to provide additional documentation, if necessary — for example, numerical control tape requisitions.
- For purchase orders, requisitions are placed on the Purchasing Action File.
- If the purchase order is for a subcontracted operation, material requisitions for the items supplied to the subcontractor are issued via the Stores Control Action File.

Relationship with other application areas

INVENTORY MANAGEMENT establishes planned orders to cover requirements (Figure 2). The lot sizing performed by the system determines order size and usually selects some sort of *economical order quantity*. The due date of the planned order is based on the earliest requirements. In the example, the planned order of 20 in period 3 covers requirements in both periods 3 and 4. The release date of the planned order is established by offsetting a fixed number of days representing the manufacturing or purchasing lead time. In the illustration a lead time of one period would cause the release date of the planned order due in period 5 to be set for period 4. INVENTORY MANAGEMENT selects a specific shop calendar date within the period in which the order is to be released. The planned order quantity and the release date are passed to MANUFACTURING ACTIVITY PLANNING (see Figure 3).

The release date may be modified in accordance with planned capacity restraints. The result is a level load on production facilities and more realistic release dates.

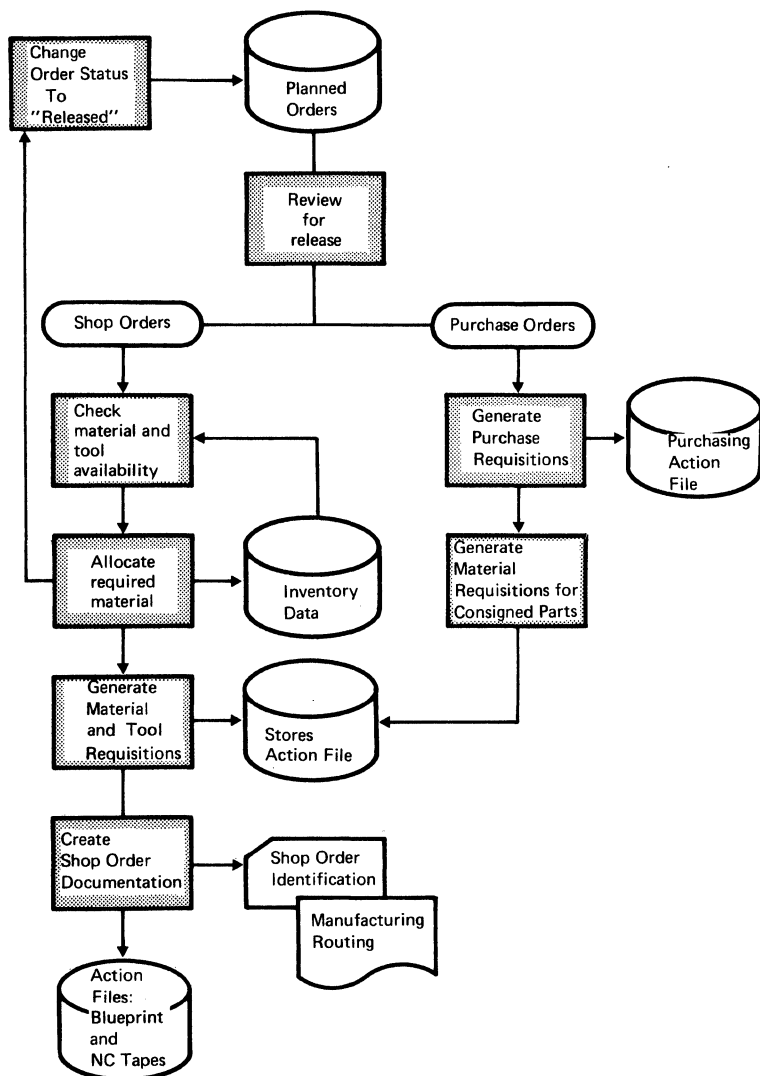


Figure 1. Basic functions of ORDER RELEASE

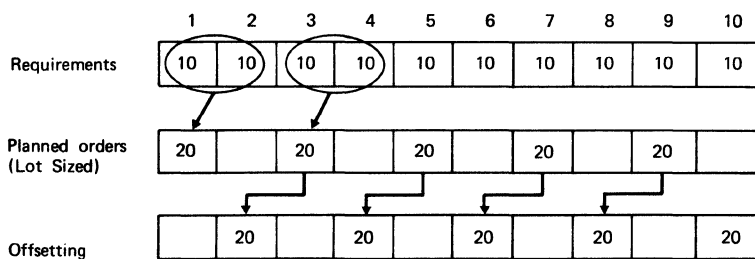


Figure 2. Planned order release dates originate in INVENTORY MANAGEMENT

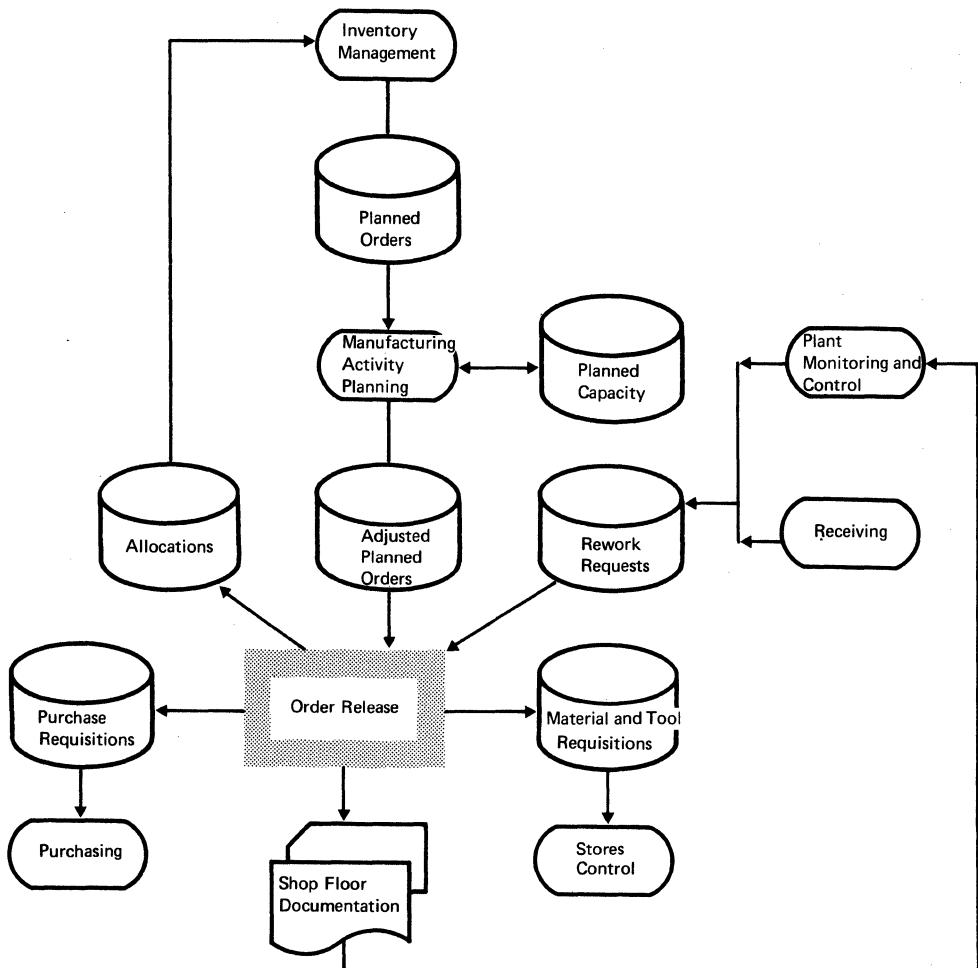


Figure 3. The relationship of ORDER RELEASE with other areas

PLANT MONITORING AND CONTROL enters rework information that requires the immediate release of new shop paperwork and the creation of new control records. The splitting of an order also necessitates the creation of new records and paperwork. Receiving has the same requirement when issuing rework orders for reclamation of off-standard purchased material.

Upon order release, tool and material requisitions are issued to STORES CONTROL via Action Files. Material is allocated to the released order and the information is passed back to INVENTORY MANAGEMENT to prevent allocation for some other purpose. Shop floor documentation used in PLANT MONITORING AND CONTROL is created to accompany the shop order.

For purchased items, requisitions are sent to Purchasing via Action Files. When a given requisition has been assigned to a supplier, it becomes a purchase order. For those items designated by the buyer, ORDER RELEASE may automatically generate the purchase order, bypassing the requisition cycle.

On a periodic basis, usually daily, the system reviews the release date of the first planned order of each item. If the planned date coincides with the dates covered by the review (usually today's date), the order is considered for order release processing.

The lead time offset used in INVENTORY MANAGEMENT and MANUFACTURING ACTIVITY PLANNING includes an allowance for the daily review and the time to prepare and gather shop documentation and the required material. From a lead time standpoint, this series of preliminary actions is considered in the same sense as an initial manufacturing operation. With this approach, release is considered on the exact date specified by the planning system.

In some cases — for example, rework on a rush shop order — the plant floor cannot wait for a daily processing cycle. Therefore, the system can be instructed to perform all release functions on a specific order at any point in time.

Adjusting Release Date

In certain cases ORDER RELEASE may alter the planned release date specified by the planning system. For example, release dates based on independent demand, such as customer orders, may be modified to reflect an adjustment for a slower or faster than forecast demand rate.

Figure 4 illustrates that on the basis of a forecast of demand, the planned release date is scheduled for shop calendar date 105. Because actual demand is less than that forecast, the inventory level at the planned release date is higher than expected. Therefore, a new release date is calculated on the basis of the current inventory level. This results in releasing the order four days later (from 105 to 109).

If demand is higher than forecast, the release date must be moved forward. This is discussed in *Chapter 5, Inventory Management*.

A change to a planned order release date is handled by INVENTORY MANAGEMENT as a *net change*. The release dates of any affected lower-level dependent planned orders (for components) are adjusted to reflect the change.

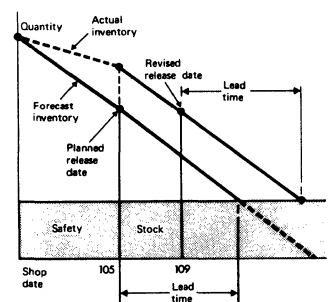


Figure 4. ORDER RELEASE may adjust a planned release date

Releasing Shop Orders

Once the planned release date has been reached, the system performs checks on the availability of materials and tools required for initial operations. Upon authorization for release, the required material is allocated and requisitions and shop order documentation are created. In many systems, allocation means setting aside materials in a “staging” area, or physically tagging them with the order number on which they will be used. In an integrated computer system such as COPICS, physical allocation is not necessary; staging is performed in the computer and “tagging” involves merely updating the system’s records.

Checking Material Availability

In many current systems, shortages of components are often discovered only when the time comes to release the order. This is why many companies release their shop orders well before the start of manufacture. Early release, however, ties up components that could be used in other shop orders. It creates artificial shortages because the “short” items will be physically allocated to shop orders before they are actually needed.

It is therefore important that the release date precede, by the shortest possible interval, the actual date that the first operation will start. The interval should be no longer than the time required to create shop documentation, pick the material, and move it to the first work center.

INVENTORY MANAGEMENT schedules lower-level components to be available when required. The relationship between component orders and assembly orders on which these components are to be used can be established by “pegging”. In Figure 5, for example, component B is pegged to high-level assemblies X and Y.

Before a planned order is released, the system checks to make sure that all lower-level components are available. This checking is accomplished by retrieving the bill of material for the assembly and calculating the component requirements, that is, determining what parts or raw materials are required for the assembly and in what quantity. The requirements are then checked against the on-hand inventory for component availability.

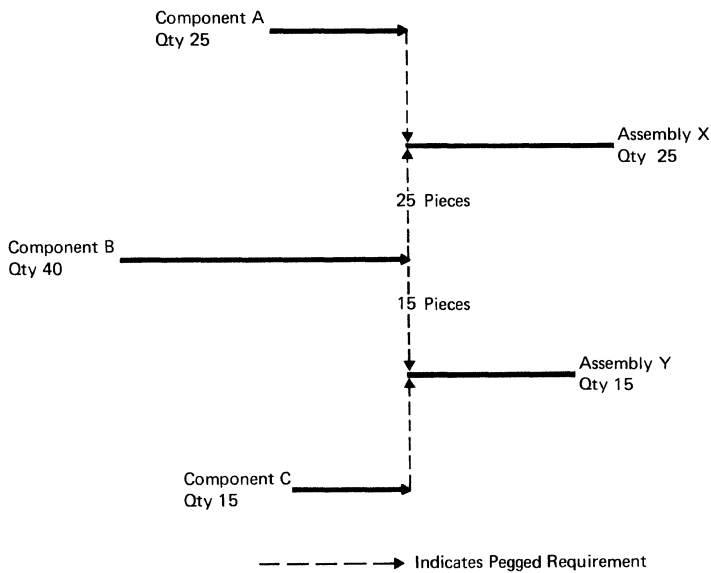


Figure 5. Pegging establishes the relationship of lower-level components with the assemblies on which they will be used

Components are not allocated if any are missing, and an order is not released until all components are available. Thus missing components do not tie up available components that can be used for other orders. If this is not desirable, the inventory administrator can specify the order as *firm*. This results in all other components being reserved or allocated in the data base pending receipt of the short component. When several parent assemblies or several orders for the same assembly are involved, components are allocated in the sequence of order priority.

If all components are not available for an order, the quantity required is entered into the unsatisfied field of all component records for that order, the order is held up, and a shortage report is prepared specifying the component(s) causing the delay. This report can be used by the inventory administrator or purchasing department to expedite the orders for missing components. Usually, INVENTORY MANAGEMENT will have notified the responsible inventory administrator of the cause of the delay well before the order release date. This is done, for example, by alarm messages that are generated the first day of delay for material from an “in-process” shop operation or a supplier.

Upon receipt of a previously short component, the system traces all other related component records to determine whether the held-up order can now be released. As soon as the last missing component becomes available, all components for the order are allocated to it, the component records are updated to show the allocation and to reduce the on-hand balance, and the order is released.

In the environment just described, physical shortages seldom exist because the system either expedites the delayed component or adjusts release schedules when delays become known. Contentions for material are solved in advance. Material shortages may, however, be detected at the time of order release in the following situations:

- When a supplier fails to deliver on the specified date or the shop fails to complete the order exactly when scheduled.
- When inventory record is incorrect. This may have been caused, for example, by pilferage. In this case the shortage is not discovered until after release (see *Chapter 11, Stores Control*).

In the typical case, the system will find all components available and proceed with other release activities. As indicated in Figure 6, the lead time offset has allowed enough time for document preparation and gathering, material picking and issuing, and transport to the first operation.

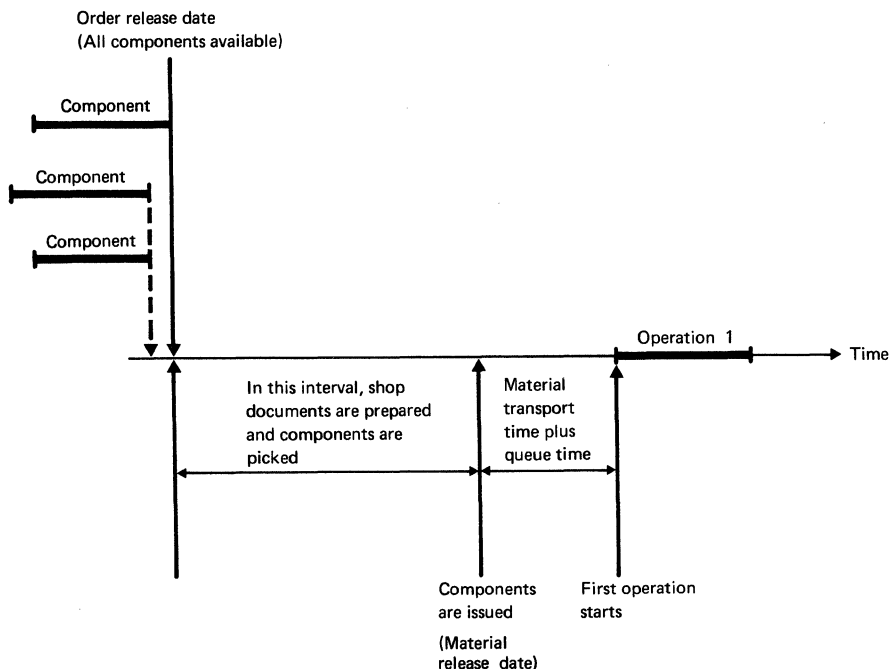


Figure 6. The order release date precedes the first operation's start date by the shortest possible interval

Delays that exceed the system's dampening factors (see *Chapter 5, Inventory Management*) are processed on a *net change* basis, and affected higher-level orders are rescheduled accordingly. In many cases delays can be absorbed without schedule changes by reducing interoperation time (see "Order Release Planning" in *Chapter 6, Manufacturing Activity Planning*) or bypassing normal receiving procedures (see *Chapter 10, Purchasing and Receiving*).

Forced release

The system automatically reschedules the start dates of late orders. However, the inventory administrator can override this rescheduling (see "Capacity Requirements Planning" in *Chapter 6, Manufacturing Activity Planning*).

Release may not have to be delayed if production can start without the delayed components. In certain cases, for example, components can be added at a later date even if this is inconvenient and more expensive (Figure 7).

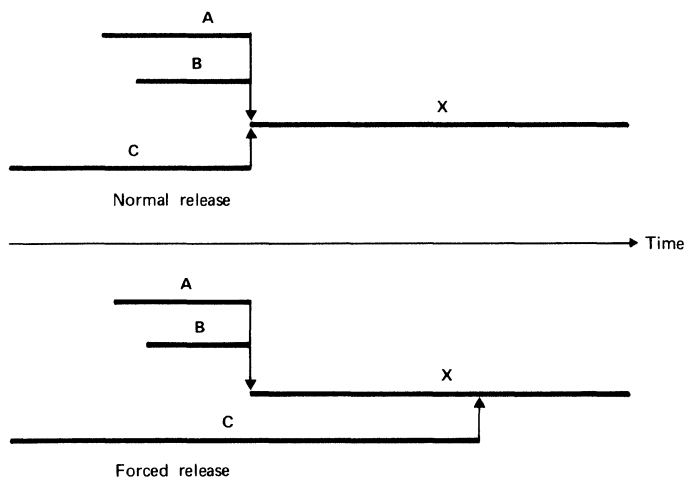


Figure 7. Forced release may result in release of the order without all components being available

In some cases off-standard material may be used to fill a shortage. The inventory administrator must authorize this via a terminal, and ORDER RELEASE indicates it when generating material requisitions.

Forced release may also be required when material is expected to arrive soon and time can be saved by initiating the document preparation and gathering cycle despite the shortage (Figure 8).

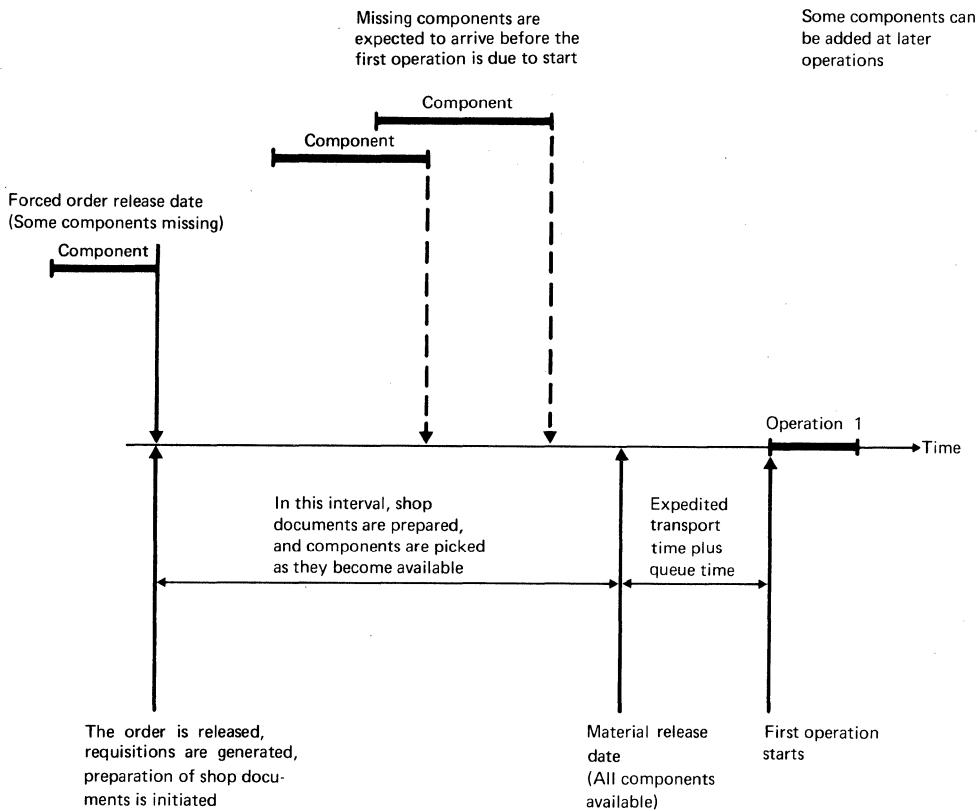


Figure 8. Forced release, directed by the inventory administrator, allows processing to start in anticipation of material availability

Thus the scheduled start date for the first operation is not affected by the component delay. Stores is warned of the missing component and no attempt is made to locate it. When it arrives, the receiving system sends it directly to the location of the shop order on the plant floor. This is accomplished using the pegging facility described in *Chapter 5, Inventory Management*.

It is conceivable that, under the regular procedure, an order might be held up indefinitely; that is, when receipt of a missing component is pending, other components originally available are allocated to other orders and are short at the time of the receipt of the former. Such orders can be “broken loose” by forced release, even though not *all* components are available. The missing components will be allocated as they become available.

In manufacturing environments where manufacturing lead time is short and there are many levels of production, time can be saved by anticipating the availability of components as a standard practice. This allows the preparing and gathering of shop documentation to overlap with the completion of the lower-level component order (Figure 9). A time interval associated with specific items subject to normal forced release specifies how far ahead of the normal release date advance release should be performed.

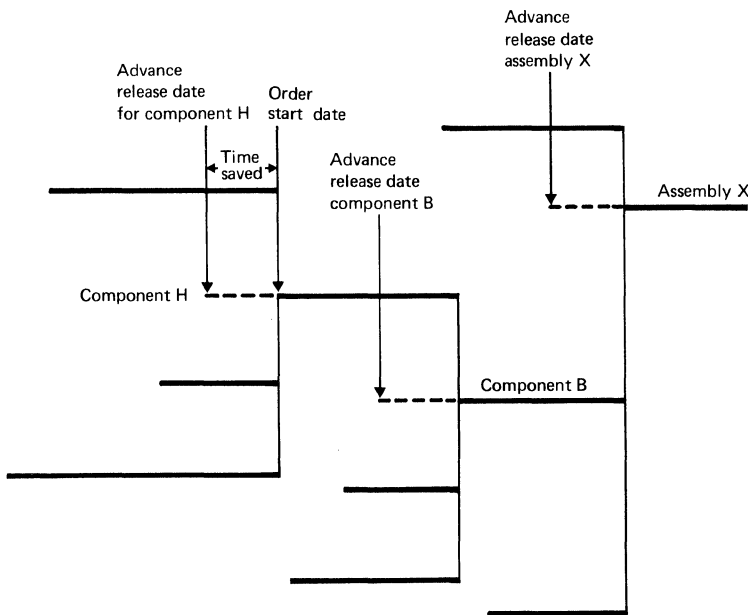


Figure 9. Advance release allows overlap of shop documentation preparation with the completion of component orders

Forced release is, however, a risky procedure, since many things can happen between release and the operation where the part is required. Some of the expected components might be scrapped or delayed. The lack of one component causes the others already issued to be tied up unnecessarily, either in a “staging” area or on the shop floor.

Generating Material Requisitions

When an order is authorized for release, a material requisition for the necessary items is generated. The requisition authorizes stores personnel to withdraw from stock the components required for the specific shop order.

For each requisition created, an entry is set up in the Picking Action File (Figure 10). This notifies stores that the items should be issued from stock. The requisition resides in the system's memory until just before the storekeeper picks the order. This allows any last minute changes, such as an order quantity adjustment, to be incorporated easily.

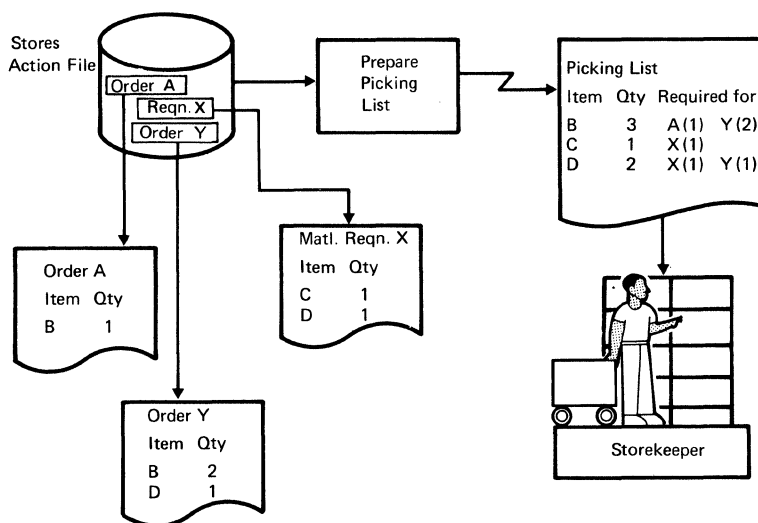


Figure 10. The system maintains in priority sequence a list of material requisitions to be picked by stores

Figure 11 shows one example of a picking list made up from a number of material requisitions as prepared by STORES CONTROL. The Action File is maintained in order priority sequence. This allows urgent requests for material to be filled quickly.

ORDER RELEASE passes information to STORES CONTROL regarding known shortages. This reduces the time the storekeeper spends searching for unavailable items. It also keeps components from being allocated to the incorrect order in cases where the orders are picked in a sequence other than allocation. Known shortages are indicated on the material requisition and on the printed picking list (see Figure 11).

STORES CONTROL arranges the picking list in a sequence that minimizes picking time. It also feeds back information indicating either that the order has been picked complete or that certain specified items could not be picked because of a physical inventory discrepancy caused by pilferage or erroneous transaction entry.

PICKING LIST NO. 2037			STOREKEEPER 4017 L.SMITH			SHOP DATE 243					
BIN LOCATION	ITEM NO.	ITEM DESCRIPTION	TOTAL QUANTITY	E.C LEVEL	ALTERNATE ITEM QTY.	QUANTITY REQUIRED FOR ORDER NOS					ENTER ADDITIONAL SHORTAGES
						41721	48032	51753	20221	43421	
A127 01	427413	BRACKET	20	E4712		20					
A127 02	290246	GUSSET	55			20		15	20		
A131 42	913222	BRACKET	16				16				
A171 29	160174	PLATE	10	E3297		10					
	160174	***SHORTAGE***	(10)			(10)					
B010 20	552437	VALVE	48	*		20		15		13	
B017 24	167224	VALVE	3			20				3	
B020 19	162221	PLUNGER	27			20				7	
B410 47	171222	VALVE	40			20			20		
C202 29	204111	SCREW	1500			400	1000	100			
C210 29	204111	SCREW	450					150	150	150	
C317 42	424324	NUT	FLOOR STOCK								
C416 19	917223	SCREW	250			40	100	100		10	
C416 25		***ALTERNATE***		914700	50				50		

TOTAL ITEMS			12			8	3	5	4	5	
TOTAL PIECES (INCLUDING ALTERNATES)			2469			550	1116	380	240	183	

STANDARD TIME			24 MINS								

Figure 11. An example of the type of picking list included in STORES CONTROL

Upon notification that the requisition could not be filled as planned, a message is automatically sent to the responsible inventory administrator. He can decide either to cancel the release or to release at a quantity lower than originally planned. The components already picked are held in a staging area until he makes a decision, and once his decision is made, the system creates a notification to return any unused components to stock. The return is processed much like a receipt; that is, the system tells the storekeeper what items are to be returned and where they are to be stored. Until all items are issued as planned, the picking list is retained by the system.

Checking Tool Availability

Requirements for tools are calculated by techniques described in *Chapter 5, Inventory Management*. This system determines the planned usage of each tool type, expressed as hours of work per time period (Figure 12). The number of hours represents a commitment for a certain number of tools.

For each type of tool a record is maintained showing the number of tools in stock, the quantity on order, and the location of all tools on the shop floor (see "Tool Control" in *Chapter 8, Plant Monitoring and Control*). When an order is about to be released, the system checks this

record for the status of each required tool type. If the required tool is available or due in the near future (before the specific operation), the system proceeds with order release. Otherwise, the inventory administrator is notified via an Action File, and release is delayed pending approval of the tool.

Final allocation of tools to orders, and the resolution of any contention for their use, is initiated by PLANT MONITORING AND CONTROL. The issue of the tool is authorized in the same way as material issues. Tool requisitions are automatically generated just before the specific operations on which they are required.

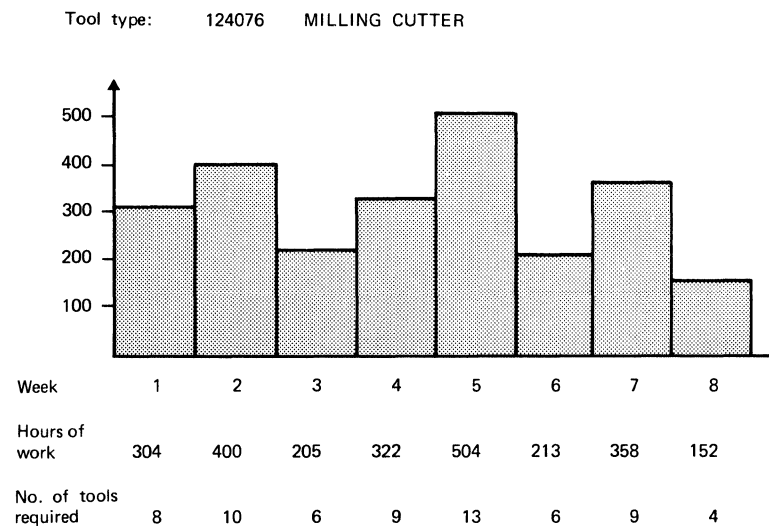


Figure 12. Tool requirements are also checked at time of order release, using records developed in MANUFACTURING ACTIVITY PLANNING

Shop Order Documentation

The documentation accompanying a released order on the shop floor normally consists of a printed manufacturing routing sheet and a shop order identification card. It may optionally contain drawings, additional instructions, or numerical control tapes. Manufacturing routings and shop order identification cards are automatically produced by the system as soon as release has been authorized.

Manufacturing routing sheets

A manufacturing routing sheet (Figure 13) indicates the work centers through which the order will be routed and describes the operations in detail. The information included is largely taken from the Manufacturing Routing File (see *Chapter 1, Engineering and Production Data Control*).

At order release time, the system checks the manufacturing routing for missing details before authorizing the printing of the routing. If any details, such as a time standard, are missing, a message is issued to Production Engineering via an Action File.

M A N U F A C T U R I N G _ R O U T I N G											
SHOP ORDER NO.	ITEM NO.	ITEM DESCRIPTION	DRAWING NO.	ENG. CHANGE LEVEL	PLANNING LEVEL	RELEASE DATE	ORDER QTY.				
42298	032471	UPPER MASTHEAD PIN	B512736	E 4079	03	243	100				
OPN. NO.	SEQ. NO.	WORK CENTER	MACH. NO.	DESCRIPTION	MATL/ TOOL NO.	OVER SEND -LAP AHEAD	SPLIT OPN.	NO.OF CONTAINERS	SET UP	TIME/ PIECE	TOTAL TIME
010	001	1000		MATERIAL CUT-OFF	817290			2			
020	002	4107	146	TURN 0.75 DIA. FOR GRINDING, FACE, CHAMFER, PART OFF AND FACE		1 50			0.33	0.15	15.33
030	003	4201		DRILL 2 HOLES X 0.125 DIA. DRILL JIG	T61724				0.16	0.04	4.16
040	004	7001		CARBURIZE AND HARDEN							
050	005	3019	121 122	FINISH GRIND 0.75 DIA.			2		0.30 0.30	0.03 0.03	3.60
060	006	8000		INSPECT							1.50
				GO/NO GO	G51388						
070		9000		STORES				2			

Figure 13. A manufacturing routing

Shop order identification cards

A shop order identification card (Figure 14) is used when reporting activity concerning the shop order as it progresses through the plant (see *Chapter 8, Plant Monitoring and Control*). The information represented includes the shop order number, item number, and order quantity. Other data, such as a brief description, may also be included.

1

072139

-

246159

25

↑ Shop Order No.

↑ Item No.

Qty.

Cardcode

Sent Ahead

072139

Shop Order Number

←

COPICS

SHOP ORDER IDENTIFICATION CARD

Figure 14. An example of a shop order identification card. This card is used in the terminal entry of data affecting the shop

For the following purposes it may be necessary to provide several copies of the identification cards:

- To ensure against loss or damage of the card
- To provide a card for each member of a labor group, or for operators working simultaneously on two machine groups when operations are overlapped
- To identify multiple containers used to transport the material

It is not necessary to issue one card for each operation on the routing.

Customer order identification

Products containing a number of options or variants may need to have the individual customer order identified during final assembly. A final assembly order showing basic customer and product identification together with a list of all variants and options required is produced (Figure 15).

Customer No.	Customer Name	Product Type	Engineering Change Level	Shop Order No.	Qty
04712	R.BROWN & CO.	410000	E 2092	12461	1
Item No.	Description	Quantity	Remarks		
410000	BASIC BILL OF MATERIAL PLUS				
019174	BASE PLATE	1			
491327	MOTOR HOUSING	1			
492243	MOTOR UNIT	1			
203214	GEAR BOX	1			
292147	CONNECTOR	1			
729173	BOLTS	10			
Inspected by					

Figure 15. A final assembly order

Requests for drawings and numerical control tapes

At the same time that the picking list is generated, the system initiates a request for any drawings that must accompany the order. The entry requesting the drawing is added to the prioritized Action File of the department controlling the drawing. This ensures that high-priority shop orders are serviced first. The Action File is maintained in the same way as already described for requisitions.

Action Files of a similar nature are also maintained for numerical control tapes, microfilm cards, and any other special documentation that is to accompany an order.

Revising shop documentation

In certain instances shop order documentation must be revised quickly in order to keep control records and manufacturing activity reporting in step. If the documents are not changed at the same time as the control records, the system may erroneously reject shop floor transactions. Up-to-date documentation also ensures that engineering changes are incorporated correctly and that the production of obsolete items is avoided.

Situations requiring shop documentation changes include:

- **Rework.** Operations are added or revised according to terminal procedures outlined in *Chapter 8, Plant Monitoring and Control*. The entry of a rework transaction may require a new routing sheet. It can be printed on a remote printing terminal located near the visual display terminal used to make the rework entry.
- **Split orders.** A split order results in a division of a released order into two or more lots. The lots are then processed as independent orders. This may be necessary when the order is considerably behind schedule and machine run time is significant. It is used in order to speed up completion of some of the pieces (see “Capacity Requirements Planning” in *Chapter 6, Manufacturing Activity Planning*). When an order is split, additional shop documentation is created to accompany the split section of the order. Corresponding control records are added to the Open Shop Order File.
- **Orders subject to engineering change.** Engineering changes that affect released shop orders are entered in a manner similar to that of rework (see *Chapter 8, Plant Monitoring and Control*). The engineer making the change can optionally request that a new manufacturing routing sheet be prepared, or he can direct that the change be printed at time of job assignment.

Reclamation and development shop orders

Some shop orders come from sources other than explosion of the master production schedule. These sources include:

- Development shop orders such as those necessary for production of prototypes
- Reclamation, or salvage, shop orders that are entered to rework off-standard receipts from suppliers or the shop floor

These orders are usually entered into the system on short notice. The procedure is similar to that used for entering a rework order (see *Chapter 10, Purchasing and Receiving*). In addition to creating shop paperwork, ORDER RELEASE must also create shop order control records.

Purchase orders are for items bought from an outside supplier. For order release purposes, subcontract orders and interplant orders (items supplied by another plant within the company) are in most respects processed the same as purchase orders and are therefore also included here.

Generating Purchase Requisitions

Planned orders from suppliers are subject to the same planning techniques as shop orders (see *Chapter 5, Inventory Management*). However, the order release procedure is different. Since normally no components are required, order release consists simply of the creation of a purchase requisition at the appropriate time. These requisitions (Figure 16) are placed in the appropriate Buyer's Action File in priority sequence. This ensures that high-priority orders are addressed first. As indicated in *Chapter 10, Purchasing and Receiving*, the buyer may simply approve the recommendation developed by the system or alter any portion of it. Purchasing recommendations are developed from information previously supplied by the buyer and maintained in the quotation records.

There are many purchase order requisitions that the buyer does not have to review before release — for instance, orders for many small, standard items. In this instance the system can automatically generate purchase orders for these items.

Subcontracted Orders

The release of subcontracted purchase orders is in some respects similar to that of shop orders and in other respects to that of purchase orders. When specific manufacturing operations are subcontracted, components or material must usually be shipped to the supplier. Therefore, the functions of checking material availability, allocation and issuing material requisitions, and supplemental documentation must be performed. This type of requisition normally is processed through Purchasing.



PRIORITY	REQUISITION NUMBER	ITEM NUMBER	ITEM NAME	DATE REQUIRED	QUANTITY	RECOMMENDED SUPPLIER	PRICE	SUPPLIER NAME	PURCHASE LEAD TIME
10	104162	199216	VALVE	196	2000	76224	1.14	SMITH CO.	25

Figure 16. A sample display from the Purchase Requisition Action File

ORDER RELEASE is the connection between the planning and implementation phases of the system. It changes the status of an order from “planned” to “released”. This means the order must now be considered a firm commitment.

The system periodically reviews the planned order file and initiates release procedures if the planned release date has been reached. This ensures that both manufactured and purchased items are ordered in time to meet their need.

Before releasing shop orders, the system checks the availability of required material. If all material is not available, the system can be instructed to delay release. This does away with the need to physically stage material in order to determine what is short for initial operations. Tool availability is also checked.

Once release is authorized, the system allocates required material. This prevents the issuance of material in short supply to other orders.

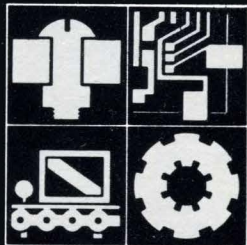
Requisitions are generated via an Action File, which holds them in priority sequence. This helps ensure that high-priority orders are filled first. Requisitions for orders that are released despite material shortages (forced release) are coded to indicate that the material is short. This prevents the storekeeper from wasting time in searching for material that is not available.

Documentation to accompany the shop order is created by the system from data previously supplied in ENGINEERING AND PRODUCTION DATA CONTROL. Data gathering coordination messages are sent, via prioritized Action Files, to departments supplying other documentation such as drawings or numerical control tapes. The system can quickly generate new documentation reflecting changes. This simplifies order control and reduces the number of incorrect manufacturing procedures.

Purchase orders are released via a prioritized Action File to the appropriate buyer. The purchase requisition usually contains a purchase recommendation developed from data previously supplied by the buyer.

Notes

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